

Contents

Chapter I: Generalities on Photovoltaic Cells

1. The Sun, an Inexhaustible Energy Source	26
1.1. Main Features.....	26
1.2. Emissions of the Sun.....	27
1.3. Constant illumination.....	28
2. Semiconductors	29
2.1. Different types of semiconductor	29
2.2. Band Structure.....	30
2.3. Intrinsic Semiconductor	31
2.4. Extrinsic Semiconductor.....	32
3. Structure of Solar Cells based on thin films	35
3.1. Substrate and the "Super Substrate" configurations	35
3.2. Different layers of thin films solar cell.....	36
3.2.1. Absorber layer.....	36
3.2.2. Buffer layer	37
3.2.3. Transparent Conductive Oxide layer (TCO)	37
3.2.4. Back Contact.....	38
3.2.5. Substratum	38
3.2.6. Anti-Reflection Layer (ARL)	38
3.2.7. Top grid.....	39
4. Principle of solar cell operation	40
4.1. Introduction	40
4.2. Electrical characteristics	40
4.2.1. The ideal solar cell	40
4.2.2. Solar cell characteristics in Practice	42

4.2.3. Quantum Efficiency and Spectral Response.....	42
4.3. Typical solar cell structures	44
4.3.1. The p-n junction	44
5. Industrial Application	47
6. Conclusion	48
References	48

Chapter II: State of Art

1. In ₂ S ₃ Thin Films Review.....	50
1.1. Introduction	50
1.2. In ₂ S ₃ thin films properties	50
1.2.1. Crystallographic structure	50
1.2.2. Phases in the In-S system.....	51
1.2.3. Optical properties.....	52
1.2.4. Electrical properties	53
1.2.5. Morphological properties.....	54
1.2.6. Technical synthesis of In ₂ S ₃ thin films	54
1.2.7. Industrial Application	55
2. SnS Thin Films Review	56
2.1. Introduction	56
2.2. SnS thin films proprieties.....	56
2.2.1. Crystallographic structure	56
2.2.2. Phase Diagram of the Sn-S System	57
2.2.3. Optical properties.....	58
2.2.4. Electrical properties	58
2.2.5. Morphological properties.....	59
3. CdS Thin Films properties	59
3.1. Introduction	59

3.2. CdS thin films properties	60
3.2.1. Crystallographic structure	60
3.2.2. Optical properties	61
3.2.3. Electrical properties	61
3.2.4. Morphological properties.....	61
4. ZnO Thin Films properties.....	62
4.1. Introduction	62
4.2. ZnO thin films properties.....	62
4.2.1. Crystallographic structure	62
4.2.2. Optical properties	64
4.2.3. Electrical properties	64
4.2.4. Morphological properties.....	65
5. SnS-Based Thin-Film Solar Cells	66
5.1. Introduction	66
5.2. Previous Works on SnS-based cells.....	66
6. Conclusion	67
References	68

Chapter III: Experimental and Characterization Techniques

1. Development techniques of thin film.....	74
1.1. Introduction	74
1.2. Chemical Spray Pyrolysis technique	74
1.2.1. Operating principle of Chemical Spray Pyrolysis	74
1.2.2. Experimental device.....	76
1.3. Definition of a thin layer.....	78
1.4. The different types of crystalline growth.....	79
1.5. Surface Tension.....	80
1.5.1. Introduction	80

1.5.2. Some observations	80
1.5.3. Surface tension.....	81
1.5.4. Surface tension of some liquids	82
1.5.5. Wetting.....	84
1.6. Conclusion	85
2. Characterization Techniques.....	85
2.1. X-ray diffraction	85
2.1.1. Rigaku Ultima IV.....	87
2.2. Raman Spectroscopy.....	88
2.2.1. Historical	88
2.2.2. Raman Spectroscopy Principle	88
2.2.3. The advantages and disadvantages of Raman Spectroscopy.....	90
2.2.4. Working method of Raman Spectrometer Principle.....	91
2.3. Scanning Electron Microscopy (SEM)	93
2.3.1. Introduction.....	93
2.3.2. Scanning Electronic Microscope Principle (SEM).....	95
2.3.3. Energy Dispersion X-ray Spectroscopy (EDS)	97
2.4. Atomic Force Microscopy (AFM)	98
2.4.1. Introduction.....	98
2.4.2. Device Description.....	98
2.4.3. Working Principle of Atomic Force Microscopy (AFM).....	99
2.4.4. Working mode of Atomic Force Microscope	100
2.4.4.1. Contact mode operating	100
2.4.4.2. Working non-contact mode	101
2.5. Photoluminescence (PL)	101
2.5.1. Introduction.....	101
2.5.2. Definition	102

2.5.3. Theory of photoluminescence.....	102
2.6. Transmittance and Absorbance measurement	105
2.6.1. Absorbance.....	105
2.6.2. Transmittance.....	108
2.6.3. Experimental apparatus.....	108
2.7. Heat treatment	109
2.7.1. Working Principle of the Oven	109
2.8. Four Point Probe Resistivity measurements	111
2.8.1. Introduction.....	111
2.8.2. Principle of the technique of 4 points	111
2.9. Capacitance-Voltage measurements	112
2.9.1. Introduction.....	112
2.9.2. Semiconductor in solution	113
3. Conclusion	114
References	114

Chapter IV: Results and Discussion

A-Optimization of deposition parameters of In ₂ S ₃ Thin Films	117
1. [S]/[In] Ratio Effect at Different Substrate Temperatures.....	117
1.1. Introduction	117
1.2. Results and discussion	117
1.2.1. X-ray diffraction analysis	117
1.2.2. Raman Spectroscopy analysis.....	120
1.2.3. Morphological analysis by SEM.....	121
1.2.4. EDS analysis	121
1.2.5. Optical Characterization	123
1.3. Conclusion	126
2. Indium Trisulfide (In ₂ S ₃) elaborated at Different Substrate Temperatures	127

2.1. Introduction	127
2.2. Experimental conditions for the preparation of thin layers of In_2S_3 by the Chemical Spray Pyrolysis method	127
2.2.1. Preparation of glass substrates	127
2.2.2. Elaboration of thin layers of indium trisulphide (In_2S_3)	128
2.3. Results and Discussions	128
2.3.1. X-ray diffraction analysis	128
2.3.2. Morphological analysis by SEM.....	130
2.3.3. Analysis by X-ray Energy Dispersion Spectroscopy (EDS)	131
2.3.4. Optical properties characterization	132
2.3.5. Analysis by Photoluminescence (PL)	134
2.3.6. Raman Spectroscopy analysis.....	135
2.4. Conclusion	136
3. β - In_2S_3 deposited by Chemical Spray Pyrolysis Method from Bi-Distilled Water Solvent and Alcohol Solvent.....	136
3.1. Introduction	136
3.2. Experimental details.....	137
3.3. Results and Discussions	137
3.3.1. X-ray diffraction analysis	137
3.3.2. Morphological analysis by SEM.....	139
3.3.3. Topographic analysis by AFM	140
3.3.4. Energy Dispersion X-ray Spectroscopy analysis (EDS)	142
3.3.5. Optical Properties of In_2S_3 Thin Films	143
3.4. Conclusion	145
B-Optimization of deposition parameters of SnS Thin Films	146
1-Effect of [S]/[Sn] ratios.....	146
1.1. Experimental details.....	146

1.2. Results and Discussion	147
1.2.1. X-ray diffraction	147
1.2.2. Raman Spectroscopy	148
1.2.3. Surface Morphology measured by SEM.....	148
1.2.4. Surface Topography measured by AFM.....	149
1.2.5. Energy Dispersive Spectroscopy analysis (EDS)	150
1.2.6. Optical properties.....	151
1.3. Conclusion	153
2. Effect of substrate temperature	153
2.1. Experimental Details.....	153
2.2. Results and Discussion	154
2.2.1. X-ray diffraction (XRD) analysis	154
2.2.2. Raman Spectroscopy analysis.....	156
2.2.3. Scanning Electron Microscopy analysis.....	157
2.2.4. Atomic Force Microscopy analysis	158
2.2.5. Energy-Dispersive X-ray Spectroscopy measurements	159
2.2.6. Electrical measurements	160
2.2.7. Optical analysis.....	161
2.3. Conclusion	162
3-Effect of substrate nature	163
3.1. Experimental	163
3.2. Results and Discussion	163
3.2.1. XRD analysis	163
3.2.2. Raman Spectroscopy analysis.....	164
3.2.3. SEM analysis and EDS measurements	165
3.2.4. Atomic Force Microscopy (AFM) analysis	167
3.2.5. Optical analysis.....	168

3.3. Conclusion	169
C-Effect of doping on the physical and chemical properties of SnS thin films	170
1- Introduction.....	170
2. SnS thin films doped with silver (Ag^+).....	170
2.1. Experimental details.....	170
2.2. Results and Discussions.....	170
2.2.1. X-ray diffraction (XRD) analysis	170
2.2.2. Scanning Electron Microscopy (SEM) analysis	172
2.2.3. Electrical properties	174
2.2.4. Electrochemical analysis: Mott-Schottky plots	174
2.2.5. Optical properties.....	175
2.3. Conclusion	177
3. SnS thin films doped with aluminum (Al^{3+})	177
3.1. Experimental details.....	177
3.2. Results and Discussion	177
3.2.1. X-ray diffraction (XRD) analysis	178
3.2.2. Surface Morphology and Composition analysis.....	179
3.2.3. Electrical properties	181
3.2.4. Mott-Schottky plots	182
3.2.5. Optical properties.....	183
3.3. Conclusion	185
4. SnS thin films doped with Iron (Fe^{2+}).....	185
4.1. Experimental Procedure	185
4.2. Results and Discussion	186
4.2.1. X-ray diffraction analysis	186
4.2.2. Morphological properties and Microanalysis	187
4.2.3. Optical properties.....	188

4.2.4. Electrical properties	190
4.2.5. Electrochemical analysis: Mott-Schottky plots	191
4.3. Conclusion	192
5. SnS thin films doped with Indium (In^{3+})	193
5.1. Thin film preparation	193
5.2. Results and Discussion	193
5.2.1. X-ray diffraction analysis	193
5.2.2. Atomic Force Microscopy analysis	194
5.2.3. Optical Absorption.....	195
5.2.4. Photoluminescence	197
5.2.5. Conductivity measurements.....	199
5.3. Conclusion	200
D. CdS, ZnO and ZnO:Al Thin Films	201
1. Introduction	201
2. CdS Thin Films	201
2.1. Structural Investigation of CdS Thin Films	201
2.2. Morphology and Microanalysis of CdS Thin Films	202
2.3. Electrical analysis of CdS Thin Films	203
2.4. Optical property of CdS Thin Film.....	203
3. ZnO Thin Films.....	204
3.1. Structural Investigation of CdS Thin Films	204
3.2. Morphology and Microanalysis of ZnO Thin Films.....	204
3.3. Electrical analysis of ZnO Thin Films	205
3.4. Optical property of ZnO Thin Film	206
4. ZnO:Al Thin Films	206
4.1. Structural Investigation of ZnO-Al doped Thin Films	206
4.2. Morphology and Microanalysis of ZnO-Al doped Thin Films	207

4.3. Electrical analysis of ZnO-Al doped Thin Films.....	208
4.4. Optical property of ZnO-Al doped Thin Film	208
5. Conclusion	209
References	210

Chapter V: SnS-based Solar Cells

1. Introduction.....	214
2. Experimental Procedure.....	214
3. J-V characteristics of cells	214
4. Result and Discussion	215
5. Conclusion	218

Chapter VI: General Conclusion

1. General Conclusion.....	219
----------------------------	-----