

## **Table of contents**

<b>Declaration</b>	i
<b>Certificate from the supervisor</b>	iii
<b>Plagiarism report</b>	v
<b>Dedication</b>	vii
<b>Preface</b>	ix
<b>Acknowledgements</b>	xi
<b>Abstract</b>	xiii
<b>List of Abbreviations</b>	xvii
<b>Table of contents</b>	xix
<b>List of tables</b>	xxv
<b>List of figures</b>	xxvii
<b>1. Chapter 1. Introduction to photovoltaic technology and theoretical background of Dye Sensitized Solar Cells</b>	1
1.1. Introduction	3
1.2. Solar Cell Technologies	4
1.2.1. Classical P-N junction silicon solar sells	4
1.2.2. Photovoltaic Generation	7
1.2.2.1. 1st generation: Crystalline Silicon (Poly-silicon or mono-silicon) solar cells	8
1.2.2.2. 2nd generation: Thin film Solar Cell (TFSC)	9
1.2.2.3. 3rd generation Solar Cells	11
1.3. Basic construction and different components of a Dye sensitized solar cell (DSSC)	17
1.3.1. Transparent conducting oxide (TCO) coated glass substrate	18
1.3.2. Photo electrode	19
1.3.3. Dye sensitizer	21

1.3.4. Electrolyte	34
1.3.5. Counter electrode	38
1.4. Basic Operating Principle of DSSC	39
References:	43
<b>2. Chapter 2. Experimental Methods and Characterization Techniques for Dye Sensitized Solar Cells</b>	69
2.1. X-Ray Diffraction analysis	71
2.2. Scanning Electron Microscopy (SEM)	72
2.3. UV-VIS spectroscopy	74
2.4. Energy Dispersive X-ray spectroscopy (EDS)	75
2.5. Raman Spectroscopy	76
2.6. Basic parameters to evaluate the performance of DSSCs:	
Solar Cell Terminologies	78
2.6.1. Open circuit voltage ( $V_{oc}$ )	80
2.6.2. Short circuit current density ( $J_{sc}$ )	81
2.6.3. Series resistance ( $R_s$ )	81
2.6.4. Shunt resistance ( $R_{sh}$ )	81
2.6.5. Fill Factor (FF)	82
2.6.6. Power Conversion Efficiency ( $\eta$ )	82
2.7. Electrochemical Impedance Spectroscopy (EIS)	83
2.7.1. Theory of Impedance	83
2.7.2. Nyquist and Bode plots	85
2.7.3. Equivalent circuit for impedance measurement of DSSC	87
References	91
<b>3. Chapter 3. Dye Sensitized Solar Cells Based on ZnO Nanostructures and Organic Dyes</b>	95
3.1. Introduction	97
3.2. Experimental Section	99
3.2.1. Structure and Working principle of DSSC	99

3.2.2. Materials used	101
3.2.3. Extraction and Preparation of Organic Dye Sensitizers	101
3.2.4. Preparation of working electrodes	103
3.2.5. DSSC assembling	106
3.2.6. Device Characterization and Measurements	107
3.3. Results and Discussion	108
3.3.1. UV-VIS absorption spectral analysis of the dyes	108
3.3.2. X-ray diffraction analysis of the ZnO film	109
3.3.3. Scanning Electron Microscope Studies	111
3.3.4. Current-Voltage Characteristics study of the cells: Solar cell efficiency measurements	112
3.3.5. Electrochemical impedance spectroscopy study of the cells	117
3.4. Conclusions	120
References	122
<b>4. Chapter 4. Application of WO<sub>3</sub> as alternative photoanode material for Dye Sensitized Solar Cells</b>	127
4.1. Introduction	129
4.2. Materials and Method	131
4.2.1. Preparation of working electrodes	131
4.2.2. Characterization and Measurements	134
4.3. Results and Discussion	134
4.3.1. Structural and phase characterization WO <sub>3</sub> photoanode	134
4.3.2. Surface Morphology study and energy dispersive spectroscopy of the photoanodes	136
4.3.3. Current-Voltage characterization of the cells	138
4.3.4. Electrochemical impedance spectroscopy	144
4.4. Conclusion	147

References	149
<b>5. Chapter 5. Role of dye co-adsorbent and blocking layer in improving the performance of DSSCs</b>	155
5.1. Introduction	157
5.2. Materials and Methods	162
5.2.1. Materials	162
5.2.2. Preparation of conventional ZnO photoanode	163
5.2.3. Preparation of photoanode with Compact ZnO layer	164
5.2.4. Assembling the devices	164
5.2.5. Characterization and Measurements	165
5.3. Results and Discussion	166
5.3.1. UV-VIS absorption spectral analysis of the dye	166
5.3.2. Structural and phase characterization ZnO compact layer	169
5.3.3. Surface Morphology study and energy dispersive spectroscopy of the photoanodes	171
5.3.4. Photovoltaic characterization of the cells	174
5.3.5. Effect of CDCA	175
5.3.6. Effect of compact ZnO blocking layer	176
5.3.7. Dark current measurement	176
5.3.8. Electrochemical impedance spectroscopy study	179
5.4. Conclusion	184
References	186
<b>6. Chapter 6. Stability Enhancement of Dye-Sensitized Solar Cells Fabricated with Gel Electrolyte</b>	195
6.1. Introduction	197
6.2. Materials and Methods	198
6.2.1. Materials	198

6.2.2. Preparation of liquid and gel electrolyte	199
6.2.3. Fabrication of the solar cells	200
6.2.4. Characterization of the DSSCs	201
6.3. Results and Discussions	201
6.3.1. Raman spectroscopy of TiO <sub>2</sub> and ZnO	201
6.3.2. Scanning electron microscope (SEM) analysis	202
6.3.3. Photovoltaic Performance of the DSSCs	203
6.3.4. Electrochemical behavior analysis of the DSSCs	207
6.3.5. Stability Study of the Cells	209
6.4. Conclusion	211
References	212
<b>7. Chapter 7. Summary and Conclusions</b>	219
<b>8. Appendix</b>	225
<b>Appendix A:</b> Dye sensitized solar cells based on pre-dye treated ZnO nanoparticles	227
<b>Appendix B: List of Research Journal Publications</b>	243
<b>Appendix C: List of Conference Presentations</b>	245
<b>9. Reprint of Selected Papers</b>	247