

TABLE OF CONTENTS

LIST OF FIGURES	viii
ABSTRACT	xii
1. Introduction	1
1.1 Introduction	1
1.2 Physics of solar cells	4
1.2.1 Semiconductor	4
1.2.2 Working of solar cells	5
1.2.3 Solar cell performance measurement parameter	9
1.3 Types of solar cells	10
1.4 Perovskite solar cells	14
1.5 Working of Perovskite solar cells	17
1.6 Lead and lead-free perovskite solar cells	18
1.7 Issues and Challenges	19
1.7.1 Stability of perovskite solar cells	19
1.7.2 Steps for stability improvement	25
1.8 Motivation	28
1.9 Scope and Objectives	29
1.10 Organisation of thesis	30
2. Methodology	32
2.1 Perovskite solar cell preparation	32
2.2 Material characterization	40
2.2.1 X-ray diffraction (XRD)	40
2.2.2 Field Emission Scanning Electron Microscopy (FESEM)	41
2.2.3 UV Vis Spectroscopy	42
2.2.4 Photoluminescence (PL) Spectroscopy	44
2.2.5 Time resolved photoluminescence (TRPL)	45
2.3 Solar cell Characterization	46
3. Improving stability of Pb and Sn based absorber layer through microstructure control	48
3.1 Broad Context	48
3.2 Introduction	48
3.3 Additive engineering	49
3.4 Solvent engineering	50

3.5 Evolution of morphology in Pb-based absorber layer	51
3.6 Achieving a large-grained and compact microstructure in Sn-based perovskite	57
3.7 Conclusion	61
4. Bilayer TiO₂/SnO₂ ETL for efficient and stable PSC	63
4.1 Broader Context	63
4.2 Introduction	63
4.3 Role of ETL in perovskite solar cell	65
4.4 Experimental	65
4.5 Result and Discussion	66
4.6 Conclusion	73
5. Triple cation absorber layer for efficient and stable PSC	76
5.1 Broader Context	76
5.2 Introduction	76
5.3 Experimental	79
5.4 Result and Discussion	79
5.5 Conclusion	86
6. Conclusion and outlook	88
6.1 Brief summary and conclusions	88
6.2 Suggestion for Future work	90
REFERENCES	92
LIST OF PUBLICATION	107
CURRICULUM VITAE	109

List of Figure

Figure 1.1 Worldwide energy source distribution (Tera Watt).....	3
Figure 1.2 Global distribution map of solar energy.....	3
Figure 1.3 Schematic of energy band diagrams of insulators, semiconductors and metals ...	5
Figure 1.4 Solar cell device structure, n-i-p (left) and p-i-n (right).....	6
Figure 1.5 Absorption of light (photons) in a semiconductor, based on their energy band gap...7	7
Figure 1.6 Solar irradiance vs. wavelength (λ) for the AM 1.5 solar spectrum incident on the earth's surface.....	8
Figure 1.7 Current density-voltage(J-V) curve of typical solar cell	10
Figure 1.8 Classification of solar cells based on the generation.....	11
Figure 1.9 The working principle of organic solar cell operation.....	13
Figure 1.10 The operational principle of Dye Sensitized solar cell (DSSC).....	14
Figure 1.11 Diagram of the evolution of the PSC.....	16
Figure 1.12 Various device architecture of perovskite solar cell.....	17
Figure 1.13 Perovskite structure showing the ABX_3 structure, b) Circuit diagram of PSC and c) schematic showing the working of solar cell.....	18
Figure 1.14 Graph showing the trend of efficiency of various types of solar cells during the past four decades.....	29
Figure 2.1 Schematic diagram and photograph of the spray pyrolysis setup.....	35

Figure 2.2 Photograph of a) solution preparation, b) spin coating of solution and c) spin coating set-up.....	36
Figure 2.3 a) Schematic showing the thermal evaporation, and b) photograph of thermal evaporation system.....	39
Figure 2.4 a) Schematic showing cell architecture and b) photograph of the cells.....	39
Figure 2.5 a) Schematic diagram of Bragg's law, b) Photograph of bench top XRD image, c) Photograph of the front view of GIXRD.....	41
Figure 2.6 Photograph showing a) front view of FESEM and b) side view of FESEM.....	42
Figure 2.7 Photograph of a) UV VIS spectroscopy setup and, b) sample holder chamber..	43
Figure 2.8 a) Schematic of the a) principle of photoluminescence and b) instrumentation and c) Photograph of PL and TRPL set-up.....	45
Figure 2.9 Photograph showing the set-up for J-V measurement.....	47
Figure 3.1 SEM images of FAMAPb(BrI) ₃ film with a) DMF only b) DMF+DMSO+CB dripping on TiO ₂ , c) on SnO ₂ , d) heated on 100°C with IR e) 120 °C without IR lamp, RA at 120 °C f) inert g) in vacuum.....	54
Figure 3.2 Comparison of color change in FAMAPb(I,Br) ₃ films, and b) XRD patterns of RAV films as a function of time.....	55
Figure 3.3 a) Absorbance and Tauc plot (inset), b) Photoluminescence and c) lifetime measurement and d) J-V curve of FAMAPb(BrI) ₃ based perovskite solar cell.....	56

Figure 3.4 a) FASnI₃ deposited with DMF solvent b) Degradation of the film as a function of time c) Film prepared with DMF: DMSO (4:1) solvent.....60

Figure 3.5 SEM images of FASnI₃ perovskite films on m-TiO₂ with addition a) SnCl₂, b) SnCl₂ +Toluene dripping, c) SnCl₂+CB, d) SnF₂ e) SnF₂+Toluene dripping, f) FASnI₃+SnF₂+CB dripping, and g) degradation of film prepared with the SnF₂ and chlorobenzene dripping as a function of time.....60

Figure 3.6 (a) XRD plot of FASnI₃ with 10% SnF₂ (b) UV-visible spectrum and Tauc plot (inset) of FASnI₃.....61

Figure 4.1 XRD plot of a) TiO₂, b) SnO₂ and c) SnO₂-TiO₂, SEM images of d) TiO₂, e) SnO₂ f) TiO₂-SnO₂.....67

Figure 4.2 Surface topography images and the roughness of a) TiO₂, b) SnO₂ and c) TiO₂-SnO₂ respectively.....68

Figure 4.3 Contact angle measurement of perovskite solution and SEM images of FAMAPbI₃ on a,d) TiO₂, b,e) SnO₂ and c,f) TiO₂-SnO₂ respectively.....68

Figure 4.4 XRD plots showing the stability of FAMAPbI₃ film with time on a) TiO₂ (T), b) SnO₂ (S) and c) TiO₂-SnO₂ (T-S) and d) degradation of FAMAPbI₃ film with days on different ETL.....71

Figure 4.5 Absorbance, Tauc plot (inset) and transmittance of a, d) TiO₂, b, e) SnO₂ and c, f) TiO₂-SnO₂ respectively.....72

Figure 4.6 Absorbance and Tauc plot (inset) of perovskite (FAMAPbI₃) film on a) TiO₂, b) SnO₂ and c) SnO₂-TiO₂. d) PL measurement of perovskite film deposited on TiO₂ (T), SnO₂

(S) and TiO₂/SnO₂ bilayer (T-S) e) J-V of PSC fabricated on different ETLs f) J-V curve of the champion cell fabricated on bilayer TiO₂-SnO₂ ETL. cell.....74

Figure 5.1 SEM images a) and b) of CsFAMAPbI₃ perovskite film on TiO₂, c) XRD showing the thermal stability of triple cation for 1000 hours.....82

Figure 5.2 a) Absorbance and tauc plot of TC perovskite, b) PL measurement of TC fresh (black) and 720 days old (red), c) life-time measurement of TC fresh (black) and 720 days old (red), d) J-V curve of TC PSC fresh (red) and 1000 hours old (blue).....86