page
Abstract ..... I
Acknowledgements ..... iii
Contents ..... v
List of Figures ..... vii
List of Tables ..... xi
List of Symbols ..... xiii
List of Abbreviations ..... xv
Chapter 1: Introduction
1.1 Motivation ..... 1
1.2 Objectives and Scopes ..... 3
Chapter 2: Literature Review
2.1 Photovoltaic Energy Conversion - A Brief History ..... 5
2.2 Dye sensitized solar cells (DSSCs) ..... 8
2.2.1 Basic structure and principles of DSSCs ..... 8
2.2.2 Electron generation, transportation, and recombination ..... 9
2.2.3 Recent progress in DSSCs ..... 10
2.3 Photodegradation for Water Treatment ..... 12
2.3.1 Decontamination of water ..... 12
2.3.2 Basic mechanism of photodegradation ..... 13
2.4 Closed shell metal oxides ..... 14
Chapter 3: Dimensionally controlled titania at sub-zero temperature, $\mathrm{ZnO}^{-\mathrm{TiO}_{2}}$ and H - $\mathrm{HfO}_{2} / \mathrm{TiO}_{2}$ nanospheres
3.1 Dimensionally controlled titania at sub-zero temperature $\left(-40^{\circ} \mathrm{C}\right.$ to $\left.-10^{\circ} \mathrm{C}\right)$ ..... 19
3.1.1 Mechanism of titania synthesized at sub-zero temperature ..... 20
3.1.2 Crystallographic analysis of titania by XRD and RAMAN ..... 21
3.1.3 Crystalline nature and optical properties of titania by TEM and UV-vis spectroscopy ..... 24
3.2 Electron Trapper $\mathrm{ZnO}-\mathrm{TiO}_{2}$ Heterojunction Solid Nanospheres ..... 27
3.2.1 Mechanism and morphological analysis of $\mathrm{ZnO}-\mathrm{TiO}_{2}$ ..... 28
3.2.2 Crystalline nature and elemental analysis of $\mathrm{ZnO}-\mathrm{TiO}_{2}$ heterojunction solid nanospheres ..... 29
3.2.3 Specific surface area study of $\mathrm{ZnO}-\mathrm{TiO}_{2}$ nanospheres ..... 31
3.3 Hydrogenated $\mathrm{TiO}_{2}$ and $\mathrm{HfO}_{2}$ nanodots ..... 31
3.3.1 Mechanism of hydrogenated $\mathrm{TiO}_{2}$ and $\mathrm{HfO}_{2}$ nanodots synthesis ..... 32
3.3.2 Morphology and structural composition of $\mathrm{H}-\mathrm{HfO}_{2} / \mathrm{TiO}_{2}$ nanodots ..... 32
3.3.3 Optical properties of hydrogenated $\mathrm{H}-\mathrm{HfO} / \mathrm{TiO}_{2}$ nanodots ..... 34
3.4 Concluding remarks ..... 35
Chapter 4: High Performance DSSC using dimensionally controlled titania at sub-zero temperature, $\mathrm{ZnO}-\mathrm{TiO}_{2}$ and $\mathrm{H}-\mathrm{HfO}_{2} / \mathrm{TiO}_{2}$ nanospheres as photoanode Materials
4.1 Titania at sub-zero temperature $\left(-40^{\circ} \mathrm{C}\right.$ to $\left.-10^{\circ} \mathrm{C}\right)$ as photoanode material ..... 37
4.1.1 Optimization of photoanode material ..... 37
4.1.2 Light scattering enhancement in photoanode films ..... 39
4.1.3 Light harvesting, charge transport and recombination ..... 41
4.2 $\mathrm{Zno}-\mathrm{TiO}_{2}$ heterojunction solid nanospheres as photoanode ..... 43
4.2.1 Nanosphere as electron trapping sites ..... 43
4.2.2 Dye loading and light harvesting capability ..... 44
4.2.3 Electron transport and mobility ..... 46
4.3 Hydrogenated $\mathrm{TiO}_{2}$ and $\mathrm{HfO}_{2}$ nanodots as photoanode material ..... 47
4.3.1 Hydrogenation, high surface area and light adsorption ..... 47
4.3.2 Dye loading ..... 49
4.3.3 Electron lifetime and charge transfer ..... 49
4.4 Concluding remarks ..... 50
Chapter 5: Graphene as a counter electrode Materials for high photo conversion efficiency
5.1 Investigation of chemically synthesized graphene as counter electrode for DSSC ..... 51
5.1.1 Synthesis and optimization of graphene counter electrode films ..... 51
5.1.2 Structural and morphological analysis of graphene ..... 53
5.1.3 Stability and performance study of counter electrode ..... 55
5.2 Carbon coated stainless steel as counter electrode for DSSC ..... 57
5.2.1. SS-Carbon material DSSC ..... 57
5.2.2 Structural, electrical and J-V performance of SS-Carbon material DSSC ..... 58
5.3 Graphene counter electrode with sub-zero temperature, $\mathrm{ZnO}-\mathrm{TiO}_{2}$ and $\mathrm{H}-\mathrm{HfO}_{2} / \mathrm{TiO}_{2}$ ..... 61
nanospheres as photoanode materials
5.3.1 Effect of working area on DSSC performance ..... 61
5.3.2 Titania at sub-zero temperature, $\mathrm{ZnO}-\mathrm{TiO}_{2}$ and $\mathrm{H}-\mathrm{HfO} / \mathrm{TiO}_{2}$ nanospheres as photoanode ..... 62
materials
5.4 Concluding remarks ..... 63
Chapter 6: Water treatment: Removal of $\mathrm{Cr}(\mathrm{VI})$ and organic contaminants
6.1 Photo-catalytic membrane ..... 66
6.1.1 Fabrication and Morphology ..... 66
6.1.2 Restoration of photo-catalytic membrane ..... 67
6.2 Photo assisted $\mathrm{Cr}(\mathrm{VI})$ reduction ..... 68
6.2.1 Sub-zero temperature $\mathrm{TiO}_{2}$ membrane and reaction rate ..... 68
6.2.2 $\mathrm{ZnO}-\mathrm{TiO}_{2}$ nanosphere and reproducibility ..... 69
6.2.3 $\mathrm{H}-\mathrm{HfO}_{2} / \mathrm{TiO}_{2}$ and industrial organic dye impurities ..... 70
6.3 Concluding remarks ..... 73
Chapter 7: Summary and Conclusions
7.1 Summary ..... 75
7.2 Concluding Remarks ..... 76
7.3 Future work ..... 76
page
Annexure A : Materials and Methods
A. 1 Materials ..... 77
A.1.1 Synthesis ..... 77
A.1.2 Solar cell ..... 77
A. 2 Methods ..... 77
A.2.1 Material synthesis ..... 77
A.2.2 Solar cell preparation ..... 78
A.2.3 Water treatment ..... 78
Publications ..... 80
References ..... 81

