Chapter wise Figure Index

Figure Number	Caption	Page Number
1.1	World energy demand and energy contributions from various energy resources	6
1.2	The contribution of non-renewable and renewable energy sources	7
1.3	Development of PV generation capacity by IEA and non-IEA PVPS countries	8
1.4	Predictions of international technology roadmap for photovoltaic (ITRPV-2018) regarding the drastic lowering of substrate thickness in monocrystalline single junction solar cells	10
1.5	Efficiency improvement of different types of research solar cell over the years	15
1.6	Schematics of solar cell classification	17
1.7	Different types of losses in solar cell	22
1.8	Schematics of fundamental losses in silicon solar cell	23
1.9	Different texturization patterns on c-Si (a)Random Conical, (b) Micro/nano pyramids, (c) Regular Inverted pyramid, (d) Porous upward pyramids, (e) Random upward pyramids, (f) Random upward pyramids, (g) Honeycomb, and (h) Grooves	28
1.10	Schematic of light trapping by textured surface in Si wafer	28
1.11	(a) SEM image of self-organized nano or micro-sized cones	30
1.12	(a) SEM image of a top surface (b) cross-section of a Cu-assisted chemical etched silicon surface	31
1.13	Schematic of destructive interference caused by anti-reflection coating	32
1.14	Different light trapping schemes using dielectric NP layer.	36
1.15	Schematic of light trapping into the absorber layer through the dielectric resonating sphere.	37
1.16	(a) St. Paul's cathedral, London, England where the WGM mode was noticed first by Rayleigh (b) Enhancement of light	38

	trapping into the thin Si solar cell using dielectric sphere through WGM modes.	
1.17	Key factors for development of efficient and affordable PV technology.	39
1.18	The developed ~30 μm thin flexible c-Si wafer by alkali etching during the research work.	41
1.19(a)	Four chamber PECVD cluster tool (CT-150) with load lock.	46
1.19(b)	Gas supply, pumping and other parts of the PECVD cluster tool.	47
1.20	Schematic of thermal evaporation system.	48
1.21	Flow chart of the performed characterization techniques for fabricated device.	49
1.22	Diffraction of X-ray from the crystalline planes.	50
1.23	Schematic of Bragg- Brentano goniometer.	51
1.24	Schematic of Basic operation of FESEM	53

Chapter 2

Optimization of back ITO layer as the sandwiched reflector for exploiting longer wavelength lights in thin and flexible (30 μm) single junction c-Si solar cells

Figure Number	Caption	Page Number
2.1	Structures adopted for fabricating the 30 μm wafer based solar cells starting from basic p-n junction.	64
2.2	(a) cross-sectional SEM image of the thin wafer showing the thickness and (b) AFM image of the post-etched silicon wafer.	68
2.3	XRD pattern of (a) undiffused 180 μm monocrystalline p-type wafer (b) undiffused 30 μm wafer (c) n-diffused 180 μm wafer from n-side and (d) n-diffused 30 μm wafer from n-side.	69

2.4	Reflectance spectrum of (a) as cut 180 μm wafer (b) 30 μm wafer and (c) n-diffused 30 μm wafer from n-side.	71
2.5	J – V characteristics of "Cell 1" and its variants: (a) primitive cell (b) after annealing in air at 600°C for 10 minutes and (c) primitive cell after firing in belt furnace at 600°C.	72
2.6	J – V characteristics of Cell 2.	73
2.7	J – V characteristics of Cell 3a, 3a and 3c.	74
2.8	Reflectance from (a) Si/Al, (b) Si/ITO-50 nm/Al, (c) Si/ITO-100 nm/Al and (d) Si/ITO-150 nm/Al structures with light impinging on the Si surface. The thickness of Al layer in all cases is 200 nm.	75
2.9	(a) FESEM image of the 30 μm textured wafer before ITO coating and (b) after ITO coating. (c) Photograph of a finished cell on textured thin wafer.	76
2.10	J – V characteristics of Cell 4a and Cell 4b	77
2.11	EQE curves for (a) Cell 3a (b) Cell 3b (c) Cell 3c and (d) Cell 4b.	78
2.12	Wavelength-dependent energy profile diagram near the junction of the cell fabricated with 30 μm wafer and having Al/50 nm thick ITO layer as the back contact (Cell 3a). Chosen wavelengths: (a) 300 (b) 400 (c) 500 (d) 600 (e) 700 (f) 800 (g) 900 (h) 1000 and (i) 1100 nm.	80
2.13	Schematics showing (a) the pathway of light through the finished cell depending upon "graded refractive index". The red dotted arrow is showing the possibility of total internal reflection. The refractive indices (RI) are for the 400 – 900 nm zone (b) scattering and multiple bounces of light with longer wavelength (red arrow) in the sandwiched BRL leading to increased OPL (red dotted arrow).	81
2.14	Wavelength dependent energy profile diagram near the junction of the textured cell fabricated with 30 μm wafer and having Al/50 nm thick ITO layer as the back contact. Chosen	82

wavelengths: (a) 300 (b) 400 (c) 500 (d) 600 (e) 700 (f) 800 (g) 900 (h) 1000 and (i) 1100 nm

Chapter 3

SHJ solar cells on adequately thin (~30 µm) c-Si wafer with unique dome like front and double layer of ITO nanoparticles as back light trapping arrangements

Figure Number	Caption	Page Number
3.1	Schematic of thin (~30 µm) SHJ cells (a) with pyramidal front texture (Cell 1) and (b) with dome shaped front surface (Cell 2).	96
3.2	Cross-sectional view of the textured thin c-Si wafer (a) before HNA treatment and (b) after HNA treatment. Partial etching of the pyramidal structure leading to dome shaped topography is evident	97
3.3	Reflection characteristics of the surface of c-Si wafer with (a) pyramidal and (b) dome shaped textures.	98
3.4	J – V characteristics of the thin SHJ cell with pyramidal (Cell 1) and dome shaped (Cell 2) front textures.	99
3.5	Morphology of the ITO layers (a) 50 nm thick flat sampleand 20 nm thick Ar plasma treated samples for (b) 5 min (c) 10 min and (d) 15 min.	101
3.6	Transmission analysis configurations with 30 µm c-Si and ITO layer/NPs	102
3.7	Transmittance curves for 30 µm c-Si wafer decorated with ITO layer/NPs	103
3.8	Back reflection measurement configurations with five different structures	103
3.9	Reflectance curves as obtained from the back layer configurations prepared on glass	104

3.10	Schematic showing the relative positions of ITO NPs at the rear side of the SHJ cells fabricated on thin n-c-Si wafer	105
3.11	J – V curves for Cell 2, Cell 3A, Cell 3B and Cell 3C	106
3.12	EQE curves for Cell 2 and Cell 3C	109
3.13	(a) J – V characteristics (Cell 3D) and (b) EQE curve for Cell 3D	110

Chapter 4

SHJ solar cells on adequately thin (~30 µm) c-Si wafer with unique dome like front and double layer of ITO nanoparticles as back light trapping arrangements

Figure Number	Caption	Page Number
4.1	Schematic for proposed structure for (a) Domain 1 and (b) Domain 2	121
4.2	Optical transmittance for domain 1 of a ~30 µm thick c-Si wafer	125
4.3	Integrated Reflectance plots as a function of dielectric layer thickness for (a) R_{bi} and (b) R_{bt} as obtained from Si/HfO_2 interface by using HfO_2/SiN_x stack as back reflector cum passivator	126
4.4	Integrated Reflectance plots as a function of dielectric layer thickness for (a) R_{bi} and (b) R_{bt} as obtained from Si/SiO_2 interface by using SiO_2/Al_2O_3 stack as back reflector cum passivator	128
4.5	(a) Reflectance (R(λ)) plot for different thickness of SiO_2 at Si/SiO_2 interface for SiO_2/Al_2O_3 double back reflector layerand (b) plot for variation of total valley area with SiO_2 layer thickness	129
4.6	Integrated reflectance plots as a function of dielectric layer thickness for (a) R_{bi} and (b) R_{bt} as obtained from Si/HfO_2 interface by using HfO_2/Al_2O_3 stack as back reflector cum passivator.	131

4.7	Reflectance (R(λ)) plot for different thickness of HfO_2 at Si/HfO_2 interface for HfO_2/Al_2O_3 double back reflector layerand (b) plot for variation of total valley area with HfO_2 layer thickness	132
4.8	Carrier generation rate plotted in log_{10} scale with respect to wafer thickness at (a) 600 nm (b) 700 nm (c) 800 nm (d) 900 nm (e) 1000 nm and (f) 1100 nm for SiO_2 (140 nm)/Al_2O_3 (100nm) BRL structure.	134
4.9	Carrier generation rate plotted in log_{10} scale with respect to wafer thickness at (a) 600 nm (b) 700 nm (c) 800 nm (d) 900 nm (e) 1000 nm and (f) 1100 nm for HfO_2 (100 nm)/Al_2O_3 (100 nm) BRL structure	136
4.10	Comparison between MAPD of active layer without BRL and with (a) SiO_2/Al_2O_3 and (b) HfO_2/Al_2O_3 BRLs with optimized thickness	139
4.11	Comparison between EQE of active layer without BRL and with (a) SiO_2/Al_2O_3 and (b) HfO_2/Al_2O_3 BRLs with optimized thickness.	140
4.12	Current density – voltage characteristics of the cells with different BRL architectures	142

Chapter 5

Hybrid inorganic-organic inverted solar cells with ZnO/ZnMgO barrier layer and effective organic active layer for low leakage current, enhanced efficiency, and reliability

Figure Number	Caption	Page Number
5.1	Schematic of the fabricated solar cells with different configurations	152
5.2	FESEM images showing topography of (a) RF grown ZnO layer (b) PLD grown ZnMgO layer and (c) cross-sectional	155

	and topographical view of hydrothermally grown ZnO film with nanorod arrays	
5.3	(a) XRD patterns for RF ZnO, PLD ZnMgO and ZnO NR layers (b) shows ZnO layer with defect states and (c) band alignments across the solar cell structure representing light induced passivation occurring at the Mg:ZnO/PCBM/P3HT:PCBM interface	157
5.4	(a) C–V characteristics of ITO/ZnO NR and ITO/ZnO/ZnMgO electrodes and (b) C–V peak shift with variation in photo excitation intensities on the ITO/ZnO NR and ITO/ZnO/ZnMgO electrode structures	158
5.5	Optical absorption spectra of (a) PEDOT:PSS/P3HT:PCBM and (b) ZnO/ZnMgO/P3HT:PCBM/PEDOT:PSS layers deposited on ITO	159
5.6	J – V curves of the four different inverted cells fabricated in this work	160
5.7	EQE plots for Cell A and Cell D	162
5.8	Plot of normalized efficiency for Cell B, Cell C and Cell D with respect to light soaking duration	163