Chapter-6
Conclusion and Future Scope

General Conclusion:

The present thesis is focused on the development of thin transparent and flexible solar cells, which have additional features such as cost-effectiveness and device flexibility. The present thesis leads a way to process the current PV technology in the direction of a thin and flexible c-Si wafer having a thickness of ~30 µm. The major challenge to using such thin wafer is the transmission loss and hence, an adequate light management scheme is required. To achieve a proper light management scheme, multifunctional materials can be used, which have to inherit superior optical as well as electrical properties such as high reactiveness, broad absorbance, good conductivity, and many more.

In this work, the author has addressed issues about the above-mentioned four fundamental requirements which would lead to PV technology being more economical, environmentally friendly, and sustainable in term of cost-effectiveness, reliability, efficiency, and device flexibility. The short recall of the whole work is mentioned below:

Chapter 1, has been devoted to the development of primitive understanding of different c-Si solar cell parameters and light management techniques to reduce the transmission and reflection loss in the solar cell.

In chapter 2, a single junction thin and flexible c-Si solar cell has been reported as a prototype. The deleterious effect of thin c-Si (mainly transmission loss) is addressed by incorporating an optimized thin ITO layer of thickness ~50 nm, which helped in light management as well as in better carrier collections, which leads to a state-of-art efficiency of ~12.23% under AM 1.5 simulated radiations. This work demonstrates the application of a thin wafer by utilizing only 1/6th (~16%) of the thickness of the standard Si wafer used in a commercial solar cell there by significantly cutting down the material cost.

In chapter 3, the advanced version of the silicon heterojunction (SHJ) solar cells are fabricated on a thin (~ 30 µm) n-c-Si wafer and results are reported as a proof-of-concept scheme. Here, two methods have been adopted to resolve the light trapping issues in thin n-c-Si substrates without compromising the device's electrical properties. Firstly, at the top a novel dome-like front texturization technique is fabricated which helped in the conformal deposition of the amorphous layer, improving the shunt resistance, open-circuit voltage, and fill factor of the cell. Secondly, at the bottom, a properly placed array of a single and double layer of ITO NPs (80-100 nm) has been incorporated, by which the back reflection of light with wavelengths > 700 nm has notably increased conversion efficiency > 15% and resulting in improved short circuit current density.

In chapter 4, the light trapping issue were addressed using theoretical estimations of two double dielectric stack structures viz. SiO_2/Al_2O_3 and HfO_2/Al_2O_3. It was observed that the dielectric stacks serve as lossless back reflector layers for thin (~30 µm) c-Si-based advanced solar cells. For optimization of dielectric thickness COMSOL Multiphysics™ computational has been used. The simulation results suggest that more than 90% of transmitted light is reflected from the Si/SiO_2 or Si/HfO_2 interface by the application of such double dielectric stack structures. These results indicate an enhancement in carrier generation rate, maximum achievable photocurrent density, and external quantum efficiency.

Lastly, in chapter 5, a combination of hybrid inorganic-organic inverted solar cells (IOSCs) with ZnO/ZnMgO barrier layer and a thicker active layer have been fabricated. As an active layer a thick layer, P3HT:PCBM (1:1) layer, has been incorporated which helps to improve the photon absorption. The use of the ZnMgO layer between P3HT:PCBM and the dense ZnO layer suppress the impact of oxygen vacancies, which improves the charge carrier mobility and lowers the leakage current. Incorporation of ZnO NR layer enhances polymer adsorption, carrier collection and protects the polymers from environmental exposure owing to its high surface-to-volume ratio and compact distribution. The cell fabricated with ZnO/ZnMgO barrier layer, in combination with ZnO NR layer, showed promising photo-conversion efficiency and durability (up to 1400 hrs of light soaking) which is better than many contemporary reports.

Future Scope:

Photovoltaic's is well known reliable renewable technology to harness solar energy to produce a significant amount of electricity to satisfy our energy needs. With the aid of extensive technological advancement c-Si-solar cell technology is the most common commercially available solar cells. Nonetheless, besides the significant advancement a huge scope of novel technological developments especially in the field of thin and flexible c-Si material and light management is required to provide low-cost, flexible solar cells. In the present thesis, we have successfully demonstrated the proof of concept and validate the potential of ITO, as thin-film and nano-particles, for light management. Few areas still have lots of future scopes of improvement.

(a) For the preparation of ITO film and NP, sophisticated equipment are required which may involve additional cost to the device. There is a need to explore the materials which require less sophisticated equipment for film deposition.

(b) The physical parameters related to the nanoparticles like shape, size, etc., need to be optimized for better back-reflection from the rear side.

(c) In thin wafer surfaces, recombination current is more due to the high surface to volume ratio. To mitigate this problem, some suitable materials can be used while controlling their layer thickness.

(d) Need of multifunctional material is required which simultaneously inherits superior optical as well as electrical properties such as high reactive index, high reflectivity, broad absorbance, good conductivity, and many more.

(e) There are several light-trapping structures are proposed and explored by learned scientific peers for thick c-Si solar cells. Now, for ~30 μm thin silicon there is a need to investigate these light-trapping structures.

(f) The major future scope of such technologies lies in the development of an advance technique to achieve such (~30 um wafer) thin wafer with high accuracy and uniformity.

(g) Other hybrid heterojunction solar cells involving organic and inorganic semiconductors may be explored to optimize the trade-off between cost and efficiency.