Chapter 7
Summary and Future Outlook

This chapter deals with the summary of work done and the concluding remarks drawn from present research work. Besides, in the last section of this chapter, the results are discussed in tabular form with the future scope for the subject of interest.
Publications:

List Of Publications

A. Peer Reviewed International Journals


B. Conferences/Workshops/Symposia:

**International**


3. Presented paper in the form of poster in an “International conference-ICSEM-2014” held at Sharda University, Great-Noida, Delhi from 6th to 8th Jan 2014.


5. Attended “International conference on physics of materials & material based device fabrication” held at Shivaji University, Kolhapur from 17th to 19th Jan 2012

**National**

1. Attended ‘5 - Day workshop on “Research Methodology” held at North Maharashtra University, Jalgaon from 20th to 24th Sept 2012.

Summary and future outlook

Of-late many efforts have been made to develop photovoltaic devices with equitable efficiency for wide spread applications using various metal chalcogenides as sensitizers. The semiconductor sensitized solar cells are receiving large attention from researchers because of its eco-friendly, low cost technology for solar energy conversion and easy-to-make solar cells. The objective of the present work was to synthesize bismuth and antimony chalcogenides for solar cell applications. Accordingly various experiments are performed and the results obtained are presented and discussed in various chapters of the thesis.

In this thesis, the bismuth and antimony chalcogenides are synthesized to explore them in solar cell applications. Initially the bismuth and antimony chalcogenides were prepared using chemical bath deposition. The structural, morphological and optical properties of the obtained materials were studied using various characterization methods. The XRD patterns show the orthorhombic phase of all stibinite family members. Morphology and optical absorption spectra were found to be influenced by deposition conditions. Further, to explore the synthesized semiconductors in SSSC, SnO$_2$ is considered as photoanode material prepared using Doctor blade method. The SSSC is successfully fabricated using earlier synthesized semiconductors as a sensitizer, SnO$_2$ as a photoelectrode, carbon coated FTO as a counter electrode and polysulphide electrolyte. The effects of deposition time of sensitizer on the performance of SSSC have been investigated.

The broad inferences which may be drawn from this investigation are as follows:

1. Bismuth and antimony chalcogenides were synthesized and characterized with different characterization techniques to study their structural, morphological and optical properties to ascertain their use as sensitizers in semiconductor sensitized solar cells.
2. The possibility of sensitization of SnO$_2$ photoanodes with synthesized chalcogenides for SSSC has been clearly established.
3. Solar cells were fabricated successfully with sensitized photoanodes obtained for three different sensitization times viz. 30, 60 and 120 min.
4. The best performance of SSSC which was obtained for photoelectrodes of 30 min of deposition time for all the sensitizing materials are tabulated as follows.
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<table>
<thead>
<tr>
<th>Photoanode/Sensitizer</th>
<th>Sensitization Time (minute)</th>
<th>$V_{oc}$ (mV)</th>
<th>$J_{sc}$ (mA/cm$^2$)</th>
<th>FF (%)</th>
<th>$\eta$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$SnO_2/Bi_2S_3$</td>
<td>30</td>
<td>369</td>
<td>0.757</td>
<td>47</td>
<td>0.43</td>
</tr>
<tr>
<td>$SnO_2/Bi_2Se_3$</td>
<td>30</td>
<td>273</td>
<td>0.329</td>
<td>50</td>
<td>0.14</td>
</tr>
<tr>
<td>$SnO_2/Sb_2S_3$</td>
<td>30</td>
<td>384</td>
<td>0.803</td>
<td>65</td>
<td>0.66</td>
</tr>
<tr>
<td>$SnO_2/Sb_2Se_3$</td>
<td>30</td>
<td>272</td>
<td>0.715</td>
<td>49</td>
<td>0.31</td>
</tr>
</tbody>
</table>

5. Among four materials the better performance was obtained for SSSC based on $Sb_2S_3$ sensitized $SnO_2$.

6. The extensive study on synthesis, characterization and photovoltaic applications of above materials opens new possibilities for the detailed study of SSSCs based on other materials.

All the objectives that were set for the present investigation have been successfully achieved.

**Future scope**

The results presented in the thesis show the influence of reaction time on the structural, morphological and optical properties of chemically synthesized bismuth and antimony chalcogenides. However, it also gives the illustration of the effect of sensitization time on the photovoltaic performance of $SnO_2$ based SSSC. Nevertheless, there is still enough scope to improve this further. The coupling of semiconductors in the present study with other semiconductors, having absorbance in shorter wavelength region, with $SnO_2$ is one of the areas for future work. Studies on various interfaces and the related charge transfer kinetics may provide better understanding into the physical phenomenon limiting the performance of SSSC. Surface state passivation (MgO or ZnS coating) of semiconductor oxide photoanode will be the future scope, to reduce recombination losses. Achievement of conformal (uniform) layer deposition of semiconductor sensitizers over photoanode to reduce back electron transfer. To study effect annealing of sensitized photoanodes on the performance of solar cells. Characterization tools like impedance spectroscopy, Ultra violet photoelectron spectroscopy, Incident photon to charge collection efficiency and Intensity modulated photovoltage spectroscopy, open circuit voltage decay may be employed to amplify the understanding on various performance limiting parameters.
Most of the studies on SSSC are based on FTO glass substrate, which is one of the obstructions in its commercialization with economy. The use of plastic or metal foil substrates is already under consideration, but more emphasis on this will be helpful for easy preparation and economic development of SSSC. The detailed study on electrochemistry of the electrolytes and catalysts, semiconductor physics from interdisciplinary groups is evidently needed for a successful basic research with the SSSC. The use of polymer electrolytes and polymer-graphene composite based counter electrodes will also be helpful for photovoltaic enhancement of SSSC. The detailed computational study on the semiconductor properties of the metal oxide electrodes and the role of surface traps in the process of electron transport is required.