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CHAPTER – VI

SUMMARY, CONCLUSIONS AND SUGGESTIONS FOR FUTURE WORK

6.1 Summary and conclusions

In the present work, thin films of CdTe and Cu doped CdTe (CdTe:Cu) (Cu = 2 wt.%, 3 wt.%, and 4 wt.%) have been deposited on 7059 corning glass substrate and fluorine doped tin oxide coated (FTO or SnO$_2$:F) glass substrate by electron beam evaporation technique. The growth conditions and dopant concentration were varied and optimized to get device quality films. The deposition was done at different substrate temperatures ($T_{\text{sub}} = \text{RT}, 100, 150$ and $200^\circ\text{C}$) and the post deposition annealing treatment was done at 300 and 400$^\circ\text{C}$ for 10 minutes.

The deposited films were uniform, pinhole free and well adherent to the substrates. Various physical properties of the deposited CdTe and CdTe:Cu thin films were systematically analyzed with different characterization techniques such as X-ray diffraction (XRD), energy dispersive analysis of X-rays (EDAX), scanning electron microscope (SEM), atomic force microscope (AFM), UV-Vis-NIR spectroscopy, photoluminescence spectroscopy and micro Raman spectroscopy. In addition, the photovoltaic properties and the photo response of the CdTe based cell structures were measured using solar simulator by illuminating the white light with a power density of 100 mW/cm$^2$. The photo response of the solar cell was measured by varying the input power intensity (60, 80 and 100 mW/cm$^2$). The observations and results obtained from these studies are discussed elaborately in this thesis.

In the first chapter, a brief note on thin films and solar cell technology were given. The properties of CdTe and its significance as absorber layer were discussed in detail. Further, detailed review on the literature of various properties of CdTe and CdS/CdTe based solar cells were presented.
Chapter 2 dealt with the elaborated details of various techniques available for thin film preparation. Electron beam evaporation technique, which was adopted in the present work for the preparation of thin films, was explained in detail. In addition, the preparation of CdTe and Cu doped CdTe thin films by electron beam evaporation technique was explained clearly with the light of various steps involved during the experimental procedure. Further, various characterization techniques that were used to study the properties of prepared thin films such as surface profilometer, X-ray diffraction, energy dispersive analysis of X-rays, scanning electron microscope, atomic force microscope, UV-Vis-NIR spectrophotometer, photoluminescence spectrometer, micro Raman spectroscopy, and electrical measurement were explained in detail.

The structural study of the films deposited at RT showed amorphous nature and turned polycrystalline with cubic phase of zinc blende structure upon increasing the substrate temperature and annealing temperature. Compositional purity of the prepared films was confirmed by EDAX study. The quantitative analysis of EDAX measurement showed that the films have Cd deficiency from their stoichiometric formulation, which confirmed the $p$-type conductive nature of deposited films. This was further corroborated by electrical measurement. The surface morphological studies by SEM and AFM showed that the films were smooth, homogeneous and crack free surface. The room temperature deposited annealed samples show significant variations with the formation of uniform netted surface over the entire film. The higher substrate temperature prepared annealed samples show the grain growth with the coalescence of the particles from the dense nucleation sites. The change in surface morphology with substrate and annealing temperatures is mainly due to the realization of different surface energy leading to crystallites of varying crystalline nature and size.
The optical transmittance study showed that the films were highly absorbing nature in the UV and visible region, and highly transparent in the IR region. The decrease in average transmittance of CdTe films with increasing Cu content is due to the increase in reflectance and/or absorbance of doped films upon Cu insertion into the film matrix. A systematic reduction in the optical energy band gap is observed with increasing the concentration of Cu, which is associated with Cu dopant induced effect leading to the production of localized states near the band edges and in the energy gap of CdTe. The observed red shift in the optical band gap highlights the advantage of CdTe films as an absorber layer in heterostructure thin film solar cells due to a decrease in the range of spectral transmission to the minimum of solar emission spectrum. The photoluminescence spectra showed the band to band radiative transition peak localized at 820 nm, which supports the result of UV-Vis-NIR spectrophotometer measurement. The observed trigonal lattice of Te peaks in the micro-Raman spectra confirmed the $p$-type conductive nature of films. In addition, the $p$-type conductive nature of the prepared films was studied by hot probe method. The low resistivity ($1\times10^3$ Ω cm) of CdTe:Cu (4 wt.%$)$ films is due to the substitutional incorporation of more efficient Cu$^{2+}$ (Cd$^{2+}$)$)$ in the CdTe lattice as compared to other films, which increase the free carrier concentration.

The photovoltaic device performance of Glass/TCO/CdS/CdTe/Au and Glass/TCO/CdS/CdTe:Cu/Au solar cell structures were studied by using solar simulator by illuminating the white light. The photovoltaic parameters such as open circuit voltage ($V_{oc}$), short circuit current ($I_{sc}$), fill factor ($FF$) and the conversion efficiency ($\eta$) of the cells increased with increasing Cu concentration. The observed low efficiency of the solar cells may be due to the nature of CdTe and CdS layers, junction formation, and grain boundary effects. However, the photo response of the device is good as the $V_{oc}$ and $I_{sc}$ is increased with increase in input power.
Thus, it can be concluded from our studies and results that the electron beam evaporation technique can produce device quality CdTe thin films under optimized preparation conditions, which are of potential use in solar cell applications. The I-V characteristics of CdS/CdTe heterostructure solar cells revealed their suitability in photovoltaic device applications.

6.2 Suggestions for future work

In order to enhance the conversion efficiency, the crystallinity of the films need to be improved further by reducing the grain boundary effect. This will be usually done by passivating the films using CdCl$_2$. The passivated films can further be activated by etching treatment which may lead to improve the photovoltaic device performance. In addition, the cell performance can be improved by adding a suitable buffer layer between TCO layer and window layer and also by including the antireflection coating. The dopant concentration may further increased or tuned to get required and sufficient carrier concentration and hence conductivity. Further, the dopants may also be varied in order to get better electrical properties. Furthermore, the preparation of nanostructured CdTe layers by electron beam evaporation technique will pave the way to tune the energy band gap in order to cover the entire solar spectrum.