ABSTRACT

Development of low cost photovoltaic solar cells with good conversion efficiency is one of the thrust areas of research. Various approaches in device structures and different techniques for fabrication have been tried to improve the efficiency of solar cells. ITO/n-Si structure is one among them. In the present study an attempt has been made to develop low cost ITO/n-Si solar cells with a good conversion efficiency using spray pyrolysis technique. For this purpose a detailed investigation has been carried out on the deposition and characterization of transparent conducting oxides (TCO) like In$_2$O$_3$ (ITO) films using spray pyrolysis technique on glass and also on silicon substrates to prepare ITO/n-Si solar cells. A versatile computer simulation program has been developed in VISUAL BASIC using both single-diode as well as double-diode models. The single-diode model program has been used to characterize the ITO/n-Si junctions whereas the double-diode model is used to characterize the illuminated output of the ITO/n-Si solar cells.

A spray pyrolysis system has been designed and fabricated for the growth of ITO films. A systematic study of the various process parameters has been carried out to get quality films under optimized deposition conditions. The films prepared by varying the process parameters have been subjected to structural, electrical, optical and morphological studies in order to optimize the process conditions. The optimized spray conditions are as follows: indium chloride and tin chloride concentration is 2 g in 100 ml, ethanol + water ratio is 90:10, air flow rate is 15 LPM, substrate to nozzle distance is 25 cm and substrate temperature is 380°C. The salient feature of the present investigation is that a very low concentration of InCl$_3$ is used for the film preparation which in turn means that the In$_2$O$_3$ films prepared are of low cost.
In$_2$O$_3$ films prepared under these conditions show polycrystalline nature with cubic bcc structure possessing (222) preferential orientation. The resistivity, transmittance and bandgap values are $1.28 \times 10^3$ ohm cm, 87.7% and 3.71 eV respectively. The films have reasonably high mobility values in the range of 30-43 cm$^2$/A/s. These values indicate that device quality 10 films of low cost can be obtained using the spray process conditions optimized in the present work.

The doping of In$_2$O$_3$ with tin improves the optoelectronic properties such as carrier concentration and resistivity and shifts the absorption edge to the shorter wavelength region. The effect of doping with different tin concentration in the ITO films prepared at different substrate temperatures has been studied. All the ITO films prepared under optimised conditions are smooth, uniform, well adherent and are polycrystalline in nature. ITO films with 5 to 15% tin doping show (222) preferred orientation whereas the films with 25% tin doping shows (400) orientation indicating that at high tin concentration the preferred orientation changes from (222) to (400). The characterisation studies on ITO films indicate that 5% tin is the optimum concentration for doping ITO, to obtain device quality films. A minimum resistivity of $3.2 \times 10^4$ ohm cm and a high transmission of more than 90% are obtained for 5% tin doped ITO films. The absorption edge for this film is shifted to the blue region showing a bandgap of 3.85 eV. The refractive index value lies in the range of 1.88 to 2.1 and found to vary with wavelength and substrate temperature. These studies indicate that device quality ITO films have been produced.

The salient feature of the present investigations is that it shows that a very low concentration of the precursors could be used to prepare the ITO films and that the films could be prepared at a relatively low temperature of 380°C which means that the ITO films prepared are of low cost. Surface morphology studies by Scanning Electron Microscopy and Atomic Force Microscopy reveal

(iii)
Interestingly different morphologies for the 10 and ITO films prepared on glass and silicon substrates.

The ITO/n-Si solar eelis with different tin doping have been prepared at different process temperatures in the range of 300-500°C. The best efficiency of 5.64% under 100 mW/cm² illumination is realized with 5% tin doped films at a relatively lower temperature of 340°C. The junction properties are studied under dark and under illumination and at different operating temperatures using the single-diode model. The possible current transport mechanism and the reason for the variation in the output characteristics are discussed in the light of SIS model. The inadequacy of the single-diode (5 parameter) model to explain the illuminated characteristics of ITO/n-Si junction is brought out and the possibility of explaining the illuminated characteristics of the junction using the double-diode (seven parameter) model is brought out.

The illuminated output parameters for the solar eelis with different tin doping and different substrate temperatures are studied using the computer simulation program with double-diode model developed in VISUAL BASIC for the present work. The simulated current-voltage (I-V) curves coincide excellently well with the experimental I-V curves, thus establishing that the double-diode (seven parameter) model is the most suitable one to be used for the characterisation of ITO/n-Si solar eelis under illumination. Using the computer simulation program, the ITO/n-Si solar eelis of poor quality (i.e., poor efficiency) is characterised and compared with the good quality ITO/n-Si solar eelis of 5.64% conversion efficiency. The study throws light on the influence of thicker insulating layer in reducing the short circuit current density leading to the very low efficiency observed for the poor eelis. The fast and accurate evaluation of the solar eelis parameters using the computer simulation program may be of great value for the large scale production units and in the quality control of solar eelis.
This thesis is organized into three main parts with three chapters under each part, supplemented by two appendices. The first part gives an introduction about TCOs, ITO/n-Si based solar cells and the details of the experimental methods of preparing ITO films and ITO/n-Si junctions and the techniques employed in characterizing them.

The second part deals with the optoelectronic and structural characterization of 10 and ITO films. The results on the ITO/n-Si junction properties have been presented on the basis of SIS model.

The third part deals with the development of a computer simulation program in VISUAL BASIC. The results on the illuminated ITO/n-Si solar cells have been analysed using the double-diode model to extract the seven parameters of the solar cell. A comparison has been made between a good cell and a poor cell to study the reasons for their behaviours so that the study may be used to large scale production process.

The chapter 10 summarises the salient features of the present work.