CHAPTER VIII

SUMMARY

From the point of view of simplicity, scalability, cost effectiveness and to develop low cost solar cells, the sol-gel route of preparing TCO thin films has been attracting the attention of several research groups in the recent years. The versatile sol-gel spin coating method has been used for depositing device quality thin films of the present study.

A novel low cost microcontroller based spin coating unit has been developed for preparing uniform thin films. The control system of the unit possesses a high precision control of spin speed and time and has provision for soft start and stop. The system utilizes the pulse width modulation technique and the switching action is achieved by a power VMOS. The spin rate can be varied from 100 rpm to 6000 rpm and spin time can be varied from 1 to 999 s.

The developed spin coating unit has been used to deposit uniform SnO$_2$, In$_2$O$_3$ and In$_2$O$_3$: Sn thin films on glass substrates and the effect of various process parameters like the gelation time, solute concentration, spin rate and spin time, number of coatings and heat treatment temperature on the properties of these films has been investigated and optimized.
For tin oxide films, the gelation time of the precursor sol has been optimized as 2-7 days using viscosity variation studies. The utility of density variation with aging to fix the gelation stage has been brought out and this has been used for fixing the gelation time of InCl$_3$ sol (needed for obtaining) of In$_2$O$_3$ films as 3-7 days. A possible explanation for the streaks of coatings seen after 7 days has been attempted in terms of particle size growth with gelation time. The turntable spin rate (co) and time (t) have been optimized as 3500 rpm and 5 s respectively for SnO$_2$ films. The same results have been obtained for the In$_2$O$_3$ films also. For both IO and TO films, the film thickness (h) is more or less
\[ \alpha \frac{1}{\omega} \]
\[ \alpha \frac{1}{\sqrt{t}} \]
agreeing with the results of simple theoretical model given by Hirasawa et al. (1997)

The structural studies point to the polycrystalline nature of SnO$_2$ films with tetragonal rutile structure and with preferential orientation along [110] orientation. The salient feature of the work is that with the optimized parameters smooth, uniform SnO$_2$ thin films with good lustre and with a resistivity of 0.03Ω cm, a transmittance of 93.63 and a band gap of 3.46eV have been obtained at a relatively low heat treatment temperature of 400°C and a short heat treatment time of 5mt/coat.
Nine coatings (thickness 269 nm) and a heat treatment temperature of 425°C have been found as optimum for the In$_2$O$_3$ films from the structural and electrical studies. The SEM and AFM studies point to smooth uniform nature of the film surface at the optimized conditions. The structural studies show that then Sol-gel spin coated In$_2$O$_3$ films are polycrystalline in nature and have bixbyte structure with [222] dominant orientation. The deterioration in the IO film properties (structural and electrical) after 9 coatings and after 425°C has been attributed to some sort of atomic rearrangement/disorder in the crystallite structure. The impurity ion scattering and the grain boundary scattering are considered as the possible scattering mechanisms. The In$_2$O$_3$ films developed in the optimized conditions has a Resistivity of 0.02Ωcm, transmittance of 75% and band gap of 3.46eV.

For the ITO films, the dopant concentrations of 5%, 10%, 15% and 20% by volume have been used and the structural, electrical properties have been investigated and 10% tin dopant concentration 7 number of coatings and 425°C have been found to be optimum. Beyond the optimized stage, there is a deterioration in structural and electrical properties possibly due to some rearrangement in the atoms/ disorder of the crystallite structure.
The best ITO films show a resistivity of $4.7 \times 10^{-3} \Omega \text{cm}$ and transmittance of 80%. The study indicates that the structural electrical and optical and surface morphological properties of ITO are very much enhanced at the 10% tin doping level. The bandgap of 3.45 eV for IO shifts to 3.62 eV for 10% tin doped film. This kind of shift in band gap towards shorter wavelength side for 10% Sn doped Indium Oxide film makes it more advantageous for solar cell fabrication technology as the band gap shifting to a higher value will enable the film to allow more visible light in which region most of the photon energy is available in the solar spectrum.

With 10% tin doped Indium Oxide films deposited by spin coating technique on n-Si substrates, the ITO/n-Si heterojunction solar cells have been fabricated with various number of coatings and at different process temperature (375 to 450°C). The junction behaviour and the solar cell output properties have been investigated. It has been found that good ITO/n-Si junctions have been formed at a relatively lower process temperature of 400°C. A conversion efficiency of 0.18% alone has been obtained for the ITO/n-Si solar cells fabricated at this process temperature. The reason for such low conversion efficiency are given with reference to other solar cells, junction interfaces and the properties of the developed ITO coatings of the present work.
Suggestions for future work

As the efficiency of the sol-gel coated ITO/n-Si solar cells of the present study have only very low efficiency, a great deal of work is needed for increasing the efficiency of the cells. For this surface modification and giving different treatment for the junctions could be tried as also improvement in film properties. The surface modification may be tried with the formation of porous silicon structure and giving potassium cyanide treatment to the silicon surface. So also studies could be made with poly crystalline and amorphous silicon substrates. All these may prove to be fertile fields of investigation.