CHAPTER -10

SUMMARY AND CONCLUSION

Numerous R&D activities are underway in the field of solar cell development for solar energy conversion efficiently and cost effectively. In this regard, develop of low cost techniques and cost semiconducting materials in thin film form are the most effective approaches. In the present work, the simple and low cost effective technique, spin coating technique through a simple instrument, also has been developed to prepare low cost semiconductors films, like SnO$_2$, SnO$_2$:F and SnO$_2$:Sb using the sol-gel route. Another simple electrochemical technology, using electrochemical etching route, has been used in making novel porous silicon structures possessing nanocrystalline silicon network to fabricate solar cells.

A simple and cost effective PC/microcontroller interface spin coating unit has been designed and fabricated. This instrument is capable of operating the turntable through a PC with various ON time and rotation speed using an user friendly VISUAL BASIC computer program. It facilitates any number of coatings to be developed, one over the other, i.e., after drying and forming coating over the dried layers. The rotation speed can be varied up to a maximum of 6000 RPM and turntable can rotate continuously up to 15 minutes for any continuous operation and make films of any desired thickness. The film thickness values, for various tin oxide films developed using this spin coating unit, are found to be inversely proportional to the spin rate ($\omega$) and also proportional to the square root of rotation time ($t$). This instrument has been successfully used in developing device quality TCO films on glass substrates and also on porous silicon substrates inorder to develop TCO/PSi solar cells.

SnO$_2$ films have been developed by using this spin coating unit through sol-gel route. A gelation time of 4 days, a spin rate of 3000 RPM and a rotation time of 15 seconds are the optimized parameters to get uniform precursor films for making SnO$_2$.
films on heat treatment. Polycrystalline SnO₂ films of 6 coatings, with tetragonal rutile structure are formed after heating at 400°C for 5 minutes per coat. These films show a resistivity of 0.03 ohm cm, transmission of 93% at 550 nm in the visible solar spectrum, and a direct band gap of 3.5 eV.

Best F-doped SnO₂ films are prepared by making 10 coatings with 7.5 at % of F doping. Low electrical resistivity of 0.0074 ohm cm and an optical bandgap of 3.85 eV are observed when heated at 375°C. The spin parameters are optimized as 3000 RPM and 10 seconds for rotation speed and time respectively. The refractive index variation is uniform all over the visible spectral region indicating the uniformity of the surface as evident from the AFM studies. The films are well crystallized at these optimized sol-gel spin coating steps when the gelation time is fixed at 4 1/2 days and total number of coatings are 10. Further, they show a high figure of merit and a high average transmission value of about 85% for this level of F-doping. The influence of F-doping is easily observed from AFM morphology which concludes that SnO₂ films doped with 7.5 at % F are of device quality nature with low resistivity and high transmittance useful for solar cell fabrication.

Polycrystalline Sb-doped SnO₂ films with preferential orientation along (110) direction are prepared by using the following sol-gel spin coatings steps: gelation period-5 days, spin rate - 3500 RPM, spin time - 10 sec, number of coatings -10. Heating at 400°C for 5 minutes with a Sb-dopant concentration of 5.2%, is seen to produce SnO₂:Sb films with optimum optical, electrical and structural properties. These films show polycrystalline nature with tetragonal rutile structure and have a bandgap of 4.1 eV which is the highest of all the SnO₂ films prepared and studied in the present work. The carrier concentration and mobility values are very high making the 5.2 % Sb doped SnO₂:Sb films highly suitable for developing efficient PSi based solar cells.

Porous silicon structures with nanocrystalline silicon network are developed at various current densities and etching times. Under the optimized conditions, electrochemical etching at 30 mA/cm² for 10 minutes is found to produce PSi structures with maximum photoluminescence. XRD studies indicates the cubic structure of PSi but
with nanocrystals on the surface of single crystal silicon wafers as observed from the broad peak at (100) orientation. Raman shift is observed in the lower wavenumber side confirming the quantum confinement effect in PSi structures. FTIR, SEM and AFM results confirm this observation. Aging in atmospheric air for two months stabilishes the PL efficiency of the PSi structure. SnO$_2$/PSi structures also show some PL after aging which reveals the fact that SnO$_2$ films can be effectively used both in passivating the PSi structure and also in developing promising SnO$_2$/PSi solar cells.

Undoped SnO$_2$, 7.5% F-doped SnO$_2$ and 5.2% Sb-doped SnO$_2$ films were formed on PSi surfaces by heating at 400°C for 10 minutes to make solar cells. Under the optimized conditions, the solar cell energy efficiencies are found to be 3.2, 5.7 and 6.8% respectively. These results confirm that the TCO films developed in the present study are having device quality and crystalline nature when prepared under the optimized sol-gel processing and spin coating steps. The observed reasonably high conversion efficiency is attributed to the incorporation of TCO films into the porous structure very effectively using the spin coating unit developed here.

There are a lot of scope for future work since the conversion efficiency has to reach a further high efficiency of about 18% realized for single crystal silicon solar cells. For this purpose, the incorporation of TCO films deep into the pores are to be effectively done and confirmed by cross-sectional studies. Heat treatment at various atmospheres like argon, hydrogen and vacuum can be given and its influence on the TCO/PSi junctions may be studied. Further, polycrystalline or amorphous silicon wafers may be used instead of single crystal silicon wafer which will reduce the fabrication cost further.
LIST OF PUBLICATIONS

Papers published in refereed journals

1. Preparation and Characterization of Nanostructured Tin Oxide (SnO$_2$) Films by sol-gel spin coating technique (Accepted for publication in the Journal, “Surface Engineering”, 2005).


Paper presented in the International/National conferences


12. Preparation and Characterization of Sol-Gel Spin Coated Antimony Doped


