# Dye Sensitized Solar Cells Behaviors of TCO Materials

*G. Ramanathan[1], K.R.Murali[2]*
*[1]Department of Physics, Sri Sai Ram Engineering College, Chennai, 600 044 India.*
*[2]Department of Theoretical physics, University of Madras, Chennai, India.*

***Abstract-The Dye sensitized solar cells (DSSC) is a good competitor for solar cells based on present technology of p-n junction. The Dye sensitized solar cells is an alternative concept of p-n junction photovoltaic devices. The principle of operation of DSSC solar cells are two processes. Charge rejection is done by photo-induced injection to the conduction band and such created carriers are transported to charge collector. By using dyes which have wide absorption band, the solar cell is capable to harvest large fraction of sunlight. In this study we have investigated the photovoltaic performance of transparent conductive oxide such as Tin oxide and Tin doped Indium Oxide (ITO) films. These films were sensitized in a dye solution of Cis-di bis ruthenium for 12 h at room temperature and carbon paste coated FTO substrate was used as a counter electrode. The photo conversion efficiency of the dye sensitized solar cell samples using Tin oxide, ITO was 0.132, 0.2294. The light intensity was 100 mW/cm$^2$***

***Keywords: TCO, DSSC, ITO films***

## 1. INTRODUCTION

Photovoltaic devices are made of either silicon or selenium. It consists of a p-n junction and is used without any bias. Photovoltaic devices are based on the concept of charge separation at an interface of two materials of different conduction mechanism [1]. Today photovoltaic technology has triggered developments in the field of solar power an alternative and renewable source of electricity. Dye sensitized solar cells or Gratzel cells are more attractive and drawn attention over the last decade because of their potentially high conversion efficiency and possible low production cost. Only after the introduction of mesoporous materials such as $TiO_2$ and using synthesized dyes the performance of these cells improved. By using porous $TiO_2$ electrodes with a Ruthenium based on a synthesized dye and Iodine/I3 redox couple in an organic solvent that Gratzel and O-Regan reported a solar cell with efficiency of 7 to 10% [2]. The mesoscopic texture of the TCO films in these cells significantly increase the cross section of light harvesting by surface anchored charge transfer sensitizers while maintaining a good contact with electrolytes. In such device ultrafast electron injection from a photo excited dye into the conduction band of an oxide semiconductor and subsequently dye regeneration and hole transportation to the counter electrode, are responsible for the efficient generation of electricity[3,4]. At present DSSC can achieve 11.1% energy conversion efficiency[5] Further the improvement of DSSC to provide long term stability at the temperature of about 80-85 $^0$C which is an important requirement for outdoor application of the DSSC,still remains a major challenge. Ever since this discovery there was a continuous approach to improve performance efficiency and stability these solar cells. In this work Tin oxide and tin doped indium oxide thin films were deposited on glass substrate by the sol gel dip coating technique using the acrylamide route. [6,7].In DSSC studies usually $TiO_2$ are used as the anode electrode but in this work TiO2 replaced by TCO materials. Transparent conducting oxide (TCO) have been widely used for a variety of optoelectronic devices, energy efficient windows, light emitting (LEDs), Flat panel Display (FPD), storage type cathode Ray tubes, Solar cells, gas sensors, photo catalysis and surface layers in electroluminescent application. Among the existing TCO Tin oxide and tin doped indium oxide is one of the most frequently used material because of its unique characteristics such as low resistivity, high optical transmittance over the visible wavelength region, excellent adhesion to substrate and chemical stability.

## II.EXPERIMENTAL

Fig shows schematic presentation of the operating principles of Dye Sensitized solar cell (DSSC). It consists of two electrodes the anode and the cathode. Theses electrodes are made from a specified glass that has a transparent conductive Oxide (TCO) coating on one side. The TCO materials is a thin layer of Tin Oxide/Tin doped Indium Oxide (ITO), the transparency of the substrate allows sunlight to enter the cell while its conductive surface collects charges.

The anode is the negative terminal of the solar cell. It essentially bears a continuous network of sintered Tin Oxide/Tin doped Indium oxide nanoparticle. This porous network offers an inner surface that is thousand times greater than the equivalent flat area and acts like a light sponge in which sunlight can get trapped. The positive terminal of the solar cells also called the cathode is coated with a catalytic material for electron transfer. In most cases this catalyst is carbon or platinum. Since a very small quantity of catalyst is needed, the electrode remains transparent. The space between the two electrodes is filled with an electrolyte that ensure charge transportation through a redox couple iodide/tri-iodide in a nitrile solvent is typically used for this purpose. Finally the two electrodes are sealed together to prevent the electrolyte solvent from

evaporating. At the heart of the system is mesoporous oxide layer composed of nanometer sized particles which have been sintered together to allow for electronic conduction to take place. Photo excitation of the latter results in the injection of an electron into the conduction band of the semiconducting materials. The original state of the dye is subsequently restored by electron donation from the electrolyte, usually an organic solvent containing redox system such as the iodide/triiodide couple. The regeneration of the sensitizer by iodide intercepts the recapture of the conduction band electron by the oxidized dye. The iodide is regenerated in turn by the reduction of triiodide at the counter electrode the circuit being completed via electron migration through the external load. The voltage generated under illumination corresponds to the difference between the Fermi level of the electron in the solid and the redox potential of the electrolyte. Overall the device generated electric power from light without suffering any permanent chemical transformation. The material of choice has been $TiO_2$ (anatase) although alternative wide band gap oxide such as ZnO [8] and $Nb_2O_5$ [9] have also been investigate in the previous study.

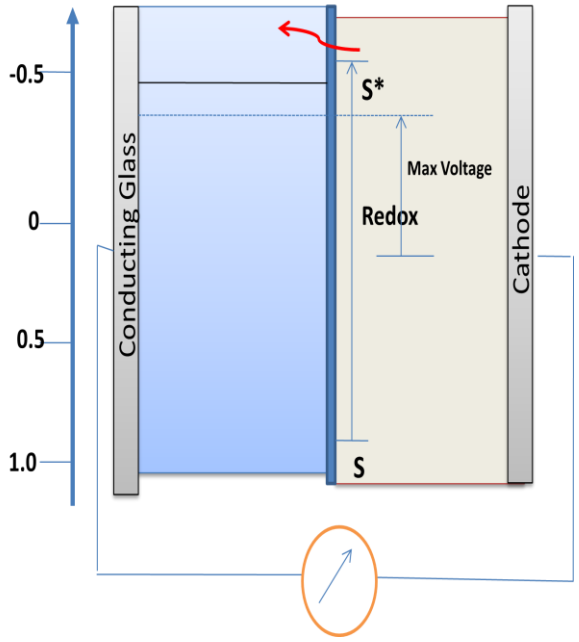



Figure 1: shows schematic diagram of Dye Sensitized solar cell

## III. RESULTS AND DISCUSSION

All the Tin Oxide/Tin doped Indium Oxide (TCO) films were sensitized in a dye solution of cis-di(thiocyanate) bis (2,2'-bipyridyl-4,4'-dicarboxylate) ruthenium (ii) (R535,N3-dye,solaronix) for 12 h at room temperature. Carbon paste coated on a FTO substrate was used as a counter electrode. The Dye sensitized solar cell (DSSC) was fabricated by clamping the dye sensitized TCO photo electrode and filling the inter electrode space by the electrolyte of 0.5M KI, 0.05M $I_2$ and 0.05M 4 tert-butylpridine using capillary force. The active cell area was $0.25cm^2$.The cell was irradiated with a 250W xenon lamp with ultraviolet and an infrared-blocking filter. The Intensity of light was 100 $mWcm^{-2}$. The important parameter of the DSSC is the photoelectric conversion efficiency. The photoelectric conversion efficiency of solar cells is the ration of the output power to the incident power. The efficiency (η) of the DSSCs can be calculated from the expression [10]

$$\eta = ( J_{sc} V_{oc} FF)/P_{in} \text{----------(1)}$$

where $J_{sc}$ is the photocurrent, $V_{oc}$ is the open circuit voltage, FF is the fill factor:

$$FF= (IxV)_{max}/J_{sc} V_{oc} \text{ ---------- (2)}$$

and $p_{in}$ is the intensity of the incident light

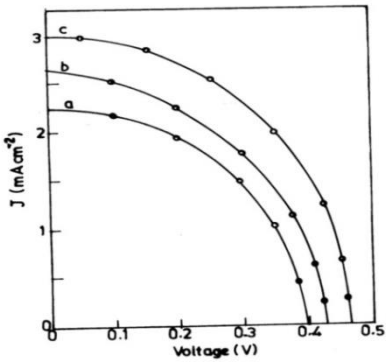



Figure 2: V-I characteristics of $SnO_2$ photo electrodes heat treated at different temperatures
(a) 350°C (b) 450°C (c) 500°C

Fig 2 shows the photocurrent-photo voltage characteristic curve of DSSCs using the $SnO_2$ films heat treated at different temperature. From the figure it is observed that the DSSC with the $SnO_2$ photo electrode formed at 500 °C shows the maximum efficiency of 1.375 % photo voltage of 0.475V and photo current of 3.0 $mAcm^{-2}$. This efficiency is lower than the efficiency reported by other research group [11].This may be due to the fact that the $SnO_2$ films in the previous report were soaked in the dye for 20 hrs and at 45°C, which resulted in better absorption of the dye on the $SnO_2$ on the surface, resulting in high efficiency. The η, FF, Voc and Jsc of the DSSCs are summarized in table 1.

Table 1.Photovoltaic performance of Tin oxide photo electrodes formed at different temperatures

| Temperature (°C) | $V_{oc}$ (V) | $J_{sc}$ (mA $m^{-2}$) | ff | η (%) |
|---|---|---|---|---|
| 400 | 0.40 | 2.25 | 0.50 | 0.750 |
| 450 | 0.42 | 2.70 | 0.56 | 1.060 |
| 500 | 0.475 | 3.00 | 0.54 | 1.372 |

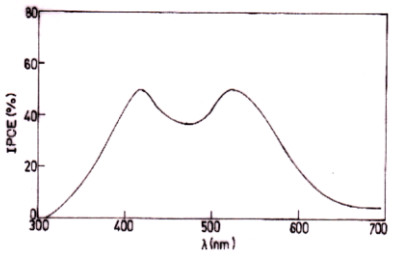
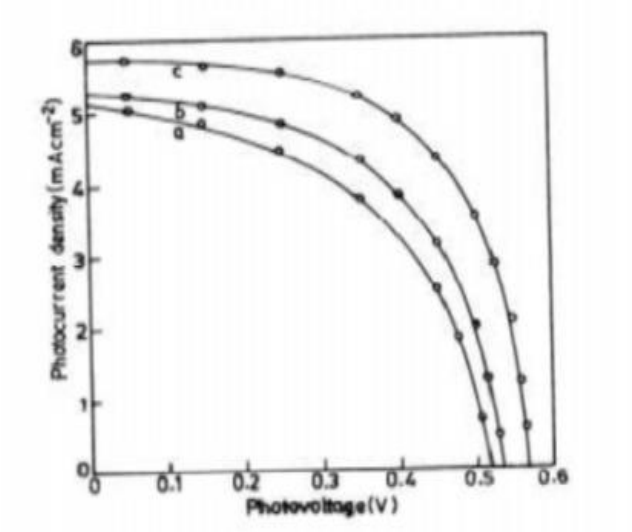


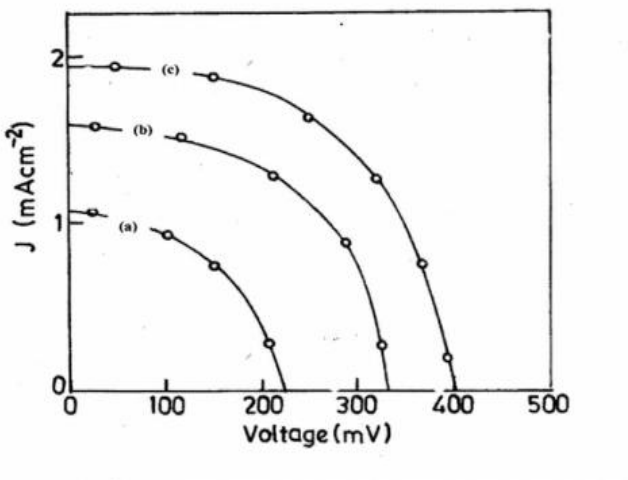

Figure 3: IPCE of $SnO_2$ films formed at 500°C

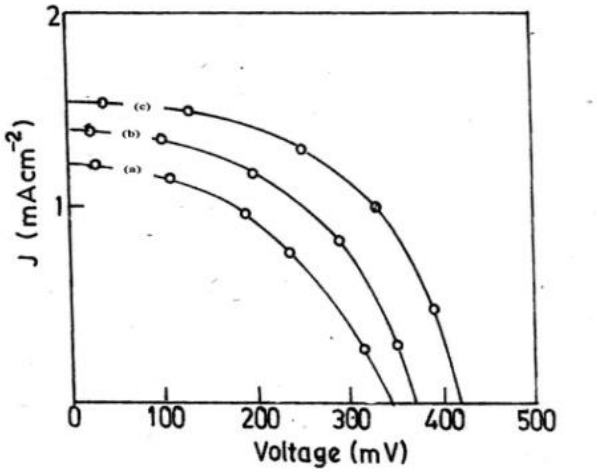
The performance of the DSSC can be quantized on a macroscopic level in terms of the incident photon to current efficiency (IPCE). The IPCE is the ratio between the number of generated charge carriers contributing to the photocurrent and the number of incident photons, as given by [11]

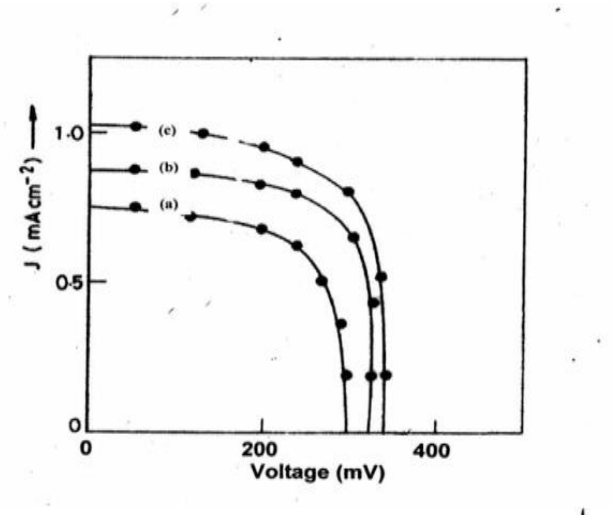
IPCE (%) = $1240 \times J_{SC} / (\lambda \times P_{in}) \times 100$ %.....(2)

where λ is the wavelength of the incident light. Fig.3 displays the wavelength distribution of IPCE for the photo electrode formed at 500°C. The photocurrent peaks occurring at approximately 410 nm are due to direct-light harvesting by Tin oxide semiconductor, in which the photo generated electrons diffuse through $SnO_2$, and the holes in the valence band are replenished directly by charge transfer from the $I_3-/I-$ electrolyte [7 ]. The IPCE value at around 526 nm has contributed by the dye absorption, corresponding to the visible $t_2 \rightarrow \pi^*$ metal- to-ligand charge transfer (MLCT). The DSSC shows reasonably high IPCE value. The IPCE spectrum shows two peaks at 410 and 526 nm, which are close to ruthenium-based dye ($N_3$-dye) absorbance. The films formed with 10% tin exhibited maximum efficiency of 2.294 % the photocurrent peaks occurring approximately 410 nm are due to direct light harvesting by $SnO_2$ semiconductor, in which the photo generated electrons diffuse through $SnO_2$, and the holes in the valence band are replenished directly by charge transfer from the I3-/I-electrolyte. The IPCE value around 526 nm has contributed by the dye absorption.




V-I characteristics of ITO photo electrodes containing10%,30%,50%,70% $SnO_2$ and formed at different temperatures (a) 350°C (b) 400°C (c) 450°C

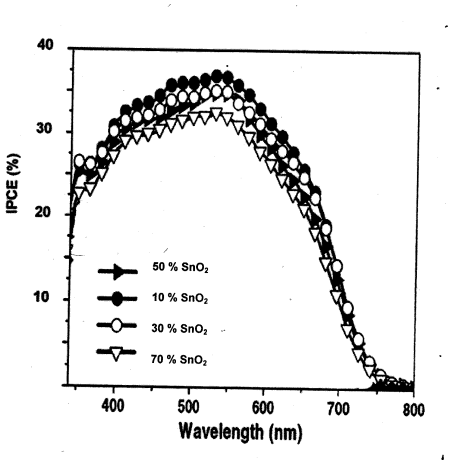



Figure 4: IPCE of ITO photo electrodes containing different concentrations of $SnO_2$ formed at 500°C

Table 3 Photovoltaic output parameters of DSSC cells fabricated with ITO photo electrodes with different concentrations of tin formed at 450°C

| Tin concentration (atomic %) | Voc mv | Jsc mAcm-2 | ff | η (%) |
|---|---|---|---|---|
| 70 | 0.33 | 1.05 | 0.73 | 0.256 |
| 50 | 0.42 | 1.55 | 0.62 | 0.403 |
| 30 | 0.40 | 1.95 | 0.68 | 0.530 |
| 10 | 0.57 | 5.75 | 0.70 | 2.294 |

## IV. CONCLUSION

$SnO_2$ and ITO films were prepared by the sol gel dip coating technique and were applied to prepare the electrodes for DSSCs. The effects of the formation temperature on the photo electrochemical properties of electrodes were investigated by the I-V and IPCE measurement. The experimental result indicate that the bulk traps and the surface stated in the electrode have important impacts on the recombination reaction which in turn influence the $J_{sc}$ and $V_{oc}$ values of the TCO based DSSCs. An optical formation temperature for $SnO_2$ electrode and ITO electrode is 500 $^0$C, 450 $^0$C because the decrease in the effect of both bulk traps and surface states at these films can maintain a lower charge recombination probability. Moreover the highest conversion efficiency (1.372%, 2.294%)

## REFERENCES

[1].Michael Gratzel "Dye Sensitized solar cells" Journal of Photochemistry and Photobiology,Vol 4. 145-153, 2003.
[2].Michael Gratzel "conversion of sunlight to electric power by nano crystalline dye sensitized solar cells" Journal of Photochemistry and Photobiology A:Chemistry Volume 164 P3-14.2004
[3] .O'Regan, B.Gratzel, M,; Nature,353 p,737- 740, 1991.
[4].Y.Chiba,A.Islam,Y.Watanable"Dye sensitized solar cells with conversion efficiency of 11.1%"Japanese journal of Applied physics Vol: 45 Part 2 Nov 24-28.
[5] G.Ramanathan,R.John Xaier and K.R.Murali "Sol gel dip coated Tin Oxide thin films" Thin film Technology 50 10588-10590,2012.
[6].G.Ramanathan,R.John Xaier and K.R.Murali "Dye sensitized solar cells with ITO films prepared by the Acrylamide sol gel route" IOSR journal of Applied physics issue 6 Vol 2 47-50.2013.
[7].Tennakone,G.R.R.Kumara,I.R.M.KottegodaV.SP.erera, Chem.Commun.15 1999.
[8].K.Sayama,H.Suguhara,H.Arakawa,Chem.Mater10 2825.1998.
[9] Easwaramoorthi Ramansamy,Won Jae,Lee Dong Yoon Lee,Jae Sung,Song,Journal of power source 165 446.2007.
[10].J.Y.Liao,K.C.Ho,Sol.Energy Mater,Sol.cells 86 229.2005.
[11].W.U.Huynh,J.J.Dittmer,A.P.Alivisatos "Hybrid nanorod Polymer solar cells" science 295 2425.2002