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# Characterisation studies on Sn$O_2$thin film coatings over solar cells

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## Abstract

**Objective:**To improve the reutilisation of heat lost due to convection from the cell to ambient air. For this purpose, initially parameter like efficiency of cell with tin oxide coating and fill factor of cell with tin oxide coating for various cross sections are envisaged.In the later stages the heat lost due to convection in predicted from the transient analysis on single cell considering it as a flat plate collector.
**Methods/Statistical analysis:**Experiments are conducted to apply a thin film-coating layer of tin oxide on solar cells (silicon wafers) by a thermal vapour process under high vacuum, followed by annealing with an objective of reducing the reflection.Theoretical analysis is carried out on single solar cell and on an array of cells (solar collector) to assess quantitatively the convection heat loss rate to the ambient air during the process of heat absorption by the cells.
**Findings:**The tests conducted with the nano-coated solar cells showed that the cell efficiency has increased from 24% without coating to 31% with an optimum coating 400 nm thicknesses has been found. The results of the theoretical analysis conducted on a single cell reveal a 2% saving in the heat loss from the cell with nano-coating compared to that without coating. As the coating thickness is increased from zero to 600nm the heat loss due to convection decreased monotonically from 461.4 to 452 W/m$^2$**.**
**Application/Improvements:**These thin films can be used in various applications like gas sensors, solar cell and sensors.
***Keywords***:$\mathrm{SnO_2}$, thin film coatings, solar cells, Thermal analysis and experimental analysis.

## 1. Introduction

Alexander-Edmond Becquerel French physicist discovered Photovoltaic effect in 1839. Charles Fritts, in 1883 when coated the semiconductor selenium with an extremely thin layer of gold to form the junctions invented first cell (1% efficient).In Bell Laboratories while conducting experiments with semiconductors, accidentally recognised sensitive behaviour of silicon doped with certain impurities to light**.**

### 1.1. Functions of solar cells

Generation of electrons and holes (charge carriers) in a light absorbing material is one of the fundamental functions of solar cell. Solar radiation is the measure of photons. Segregation of the electrons and flow to a conductive contact to transmit electricity is another fundamental function of solar cell.

### 1.2. Solar radiation

SRI plays a vital role in working of solar collectors. Solar collector is an arrangement of array of solar cells in series and parallel. SRI varies along with time of the day. As the SRI increases the heat accumulation also increases in the HPVTC.

### 1.3.Photovoltaic thermal collector

Conventional photovoltaic systems use only the photons from light to generate current. Excess heat accumulates.Thus a photovoltaic thermal collector system is introduced which not only uses the photon energy but also the thermal energy accumulated in the cell through a heat transfer fluid.

### 1.4. Natural convection

Heat transfer between any two different mediums is called as convection. In this work heat transfer from solid to ambient air is considered. Heat transfer taking place in atmospheric conditions without and external aid is said as

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free convection or natural convection. During this natural convection the velocity at the fluid layers is considered as zero (no slip conditions).

### 1.5. Rayleigh number

It is defined as a dimensionless number used to the type of fluid flow. Depending upon the value of Rayleigh number the Nusselt number equation is considered for determining the convective heat transfer coefficient.

$$Ra_L = \frac{g\beta\Delta T L_c^3 \rho^2 C_p}{\mu k} \quad (1)$$

### 1.6.Solar cell

Replacements of fossil fuels with in expensive devices have diverted attention of researchers towards solar cells. These devices meet the needs of both the electronics and energy industries and do not require expensive manufacturing process. In [1] research proposal is to explore that with a little human ingenuity, abundant energy can be converted to adaptive range of applications. Further development of thin film, dye synthesised and organic solar cells enhanced the cell efficiency. The development is basically hindered by low conversion efficiency, heat imbalance, blocking of layers, effect of geographic location, cost, reducing payback period and electrical imbalance. In [2][3]discussed the current scenario of solar cells. Thin film solar cells demonstrate 10-12% of efficiency but their performance is poor under higher temperature. Nano crystal solar cell is highly stable under high temperature conditions but their efficiency is limited to 7-8%. Concentrated and Perovskitesare highly stable and efficient (40-30) %. Journal of [4] emphasize the progressive development in the solar cell technologies and techniques to improve the overall performance. Solar energy is equipotential to replace the fossil fuels and significant in reducing greenhouse gas emissions. Accurate information on solar radiation is very essential for energy systems based on solar source. Thus [5] have measured hourly global solar radiation data in India during May 2015 as shown in Table 1.

*Table 1. Solar radiation intensity values for the month of May 2015*

| Time (hrs.) | Solar radiation intensity ($Wm^{-2}$) | Time (hrs.) | Solar radiation intensity ($Wm^{-2}$) |
|---|---|---|---|
| 6:00 | 8 | 12:05 | 833 |
| 7:00 | 71 | 12:10 | 815 |
| 8:00 | 232 | 12:15 | 829 |
| 9:00 | 442 | 12:20 | 825 |
| 10:00 | 616 | 12:25 | 798 |
| 11:00 | 733 | 12:30 | 841 |
| 12:00 | 819 | 12:35 | 824 |
| 13:00 | 824 | 12:40 | 817 |
| 14:00 | 838 | 12:45 | 763 |
| 15:00 | 425 | 12:50 | 630 |
| 16:00 | 477 | 12:55 | 743 |
| 17:00 | 122 | 12:60 | 867 |
| 18:00 | 114 | 13:15 | 874 |
| 19:00 | 31 | 13:25 | 862 |
| 20:00 | 7 | 13:40 | 856 |

The authors have taken solarradiation data for every five minutes during 6:00 to 20:00. Polynomial curve fitting method was used for smoothing the data obtained. The polynomial curve fitting and data sampling was done in MATLAB. In [6] fabricated solar cells using tin oxide $SnO_2$ deposited onto silicon substrate by Atmospheric Pressure Chemical Vapour Deposition (APCVD) technique. In this paper, the effects of interfacial oxide layer thickness δ on the

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efficiency and open circuit voltage of the $SnO_2/SiO_2/Si$ (N) solar cells. From the analysis, it is found that the efficiency of the cells increases at first with the interfacial oxide layer thickness δ, and after acquiring a maximum value falls with a further increase of δ. We have experimentally optimized the interfacial layer thickness for maximum efficiency. In this paper, the effects of interfacial oxide layer thickness δ on the efficiency and open circuit voltage of the $SnO_2/SiO_2/Si$ (N) solar cells.

**1.7. Coatings**

Silicon solar cells have been fabricated with single and double layer silicon oxide, titanium oxide anti-reflecting (ARC) coating. In [7] stated the significant improvement in solar cell efficiency with the application of ARC. The solar cell without ARC would only transmit about 70% of IR and 50% of UV portions of the sunlight into the cell. Although other factors such as recombination, poor contacts also influence the solar cell efficiency but overall performance of an actual solar cell is limited by light trapping conditions. Due to application of ARC lowest reflection of light is imparted. Metal oxides are one of the best materials as ARC. Oxides can be used for the purpose of light management, passivation of electrical defects, photo-carrier generation, charge separation, and charge transport in a solar cell. In [8] not only suggest wide range of properties of oxides, but also demonstrates the versatility of oxides as functional materials. In [9] research specified the properties of tin oxide Thin-Nano films deposited on glass substrate. Thermal evaporation unit is used to fabricate these films. The films are characterized by recording their transmittance measurements, X-ray diffraction (XRD) patterns, scanning electron microscope (SEM) images and energy dispersion X-ray analysis. It is found that the films have high transmittance and non-sharp absorption edge. XRD diffract to grams showed that the films are amorphous and the SEM micrographs depicted that the surfaces are smooth, uniform and well covered with the material. Porosity, thermal resistance, grain boundaries are the three properties which reduces heat transfer through polycrystalline materials. Thermos physical properties play an important role in the fabrication process. Thermal conductivity of bulk $\mathrm{SnO_2}$is 40 $\mathrm{Wm^{-1}K^{-1}}$.In[10] considered $\mathrm{SnO_2}$powder with high purity (Aldrich) for fabricating Nano films. The thermal conductivity of these films is found to be 0.6 $\mathrm{Wm^{-1}K^{-1}}$at room temperature.

**1.8.Solar panels**

Solar panels work on the principle of photovoltaic effect. Solar panels are made of array of solar cells, a semiconductor device which converts photons directly into thermal and electrical energies. One of the major issues in converting photons into energy is the temperature effect of solar cells. Thus cooling methods has become a must for good performance. In [11] prolonged his research on solar panel with base fluid as air is considered for the simulations. Calorific energy is generated during the photovoltaic conversion of the solar module; this heating is harmful for the photovoltaic cell output. The idea to exploit this phenomenon by the combination of the photovoltaic module with a thermal system to form the photovoltaic thermal (PVT) hybrid collector which will generate electricity and heat, at the same time.

The thermal system consists of a rectangular aluminium reservoir that is mounted to the backside of PV panels, through which water flows. The new design of a PVT collector with single stage inverter is proposed by [12] since heating is inevitable PV cells. Analysis of the proposed photovoltaic-thermal solar panel design was performed using PSIM and ANSYS software. The ambient temperature was considered to be 298K and the temperature distribution along a 2D model obtained in the simulation was 326K. In [13] investigated the Thermal Performance of High-Concentration Photovoltaic Solar Cell Package. Traditional solar cells replaced with a concentrating-light module on top are called as concentrated photovoltaic solar cells. Input parameters considered are 910$\mathrm{Wm^{-2}}$. Around 20% increase in efficiency is obtained under ambient conditions as 30℃. The maximum temperature of concentrated module attained is 44.25℃. Here, a two phases, three dimensional models were made for evaporation as well as condensation process in solar still by using ANSYS CFX method to simulate the present model. In [14] diagnosed a good agreement with experimental and simulated results. The ambient temperature is 302K and maximum temperature of water is 582K. Using computational fluid dynamics solar flat plate collectors for circular pipe configuration is fabricated. Experimental and theoretical results of flow and temperature distribution for solar flat plate collector are compared. Mass flow rate of water is 0.025kgs$^{-1}$and inlet temperature is 306K. The collector is placed at 45° tilt angle. Ambient temperature 299K, solar radiation intensity 875$\mathrm{Wm^{-2}}$ outlet temperature obtained is 307K. Thus enhancing heat absorption by the working fluid reduces the overall temperature of the absorber plate while improving the efficiency of the collector. In [15] conducted experiments on thermal collector with above

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mentioned conditions and mentioned the results under ambient temperature 20°Cthe outlet temperature 38.2°Cis obtained.

The prediction and measurement of the thermal conductivity k, of crystalline materials, particularly in those with Nano-scaled structural features, continues to pose a challenge to the heat transfer community. In [16] reviewed the determination of thermal conductivity of thin films. The thermal conductivity of bulk material varies compared to Nano films. Theoretical and experimental methods for calculation of these thermal conductivity values are also stated. The performance of solar photovoltaic cells depends on its design, material properties, and fabrication technology. In [17] presented a comparative study of mono layer silicon solar cell simulation result designed by COMSOL Multiphysics and the fabrication result of this solar cell. In software we get the efficiency of the solar cell is 27% - 28% and after fabrication of that cell the efficiency is 11%-12% using sun simulator. In [18] AR coating showed that the AR coating is highly compatible with the polycrystalline silicon solar cells. About 40-50% improvement in the short-circuit current of p on n polycrystalline cells has been measured. The coating may be highly suited to large-scale production flow-cost polycrystalline silicon solar cells for terrestrial application [19]. In [20] investigated experimentally and theoretically the results of flow and temperature distribution in a solar collector panel with circular tube configuration and compared with CFD simulated results. Fluid flow and heat transfer in the collector panel were studied by means of computational fluid dynamics. In [21] thermal analysis of solar honey comb facades at different configurations was evaluated in order to define the performance and thermal ventilation of as well as the electrical properties. CFD analysis was done and compared with the experimental data from the lab.

## 2. Experimental study

$SnO_2$ coatings of 100nm to 600nm thickness are applied on Corning 7059 glass substrate of 76.2×50×1.2mm size using thermal vapour process. This process is carried less than $2.5\times10^{-8}$ bar vacuum condition; the tin oxide vaporizes and sublimes to form a nano film on the glass substrate. Subsequently the nano film is oxidised by an annealing process at a high temperature. Vacuum chamber consists of Quartz crystal which is used to monitor the thickness of the deposited film and also to control the rate of evaporation.

*Table 2.Specifications of the thermal evaporation system*

| |
|---|
| Uses Tungsten or Molybdenum filaments to heat the evaporant |
| Ultimate chamber pressure $2.5\text{x}10^{-8}$bar |
| Typical filament currents are 100-200Amps |
| Maximum deposition thickness that can be achieved is 900nm. |
| Substrate temperature can be increased up to 50°C. |

*Table 3. Solar Cell Specifications*

| ***Description*** | ***Characteristics value*** |
|---|---|
| ***Maximum power*** | ***9.00 mW*** |
| ***Maximum power voltage*** | ***3 V*** |
| ***Maximum power current*** | ***3 mA*** |
| ***Short circuit current $I_{sc}$*** | ***1.5 mA*** |
| ***Open circuit voltage $V_{OC}$*** | ***2.5 V*** |
| ***Dimensions*** | ***$76.2\times 50 \times 0.4$ mm*** |

Table 2 represents the specifications of the thermal vapour unit used to fabricate the thin film coating placed on the solar cell. Table 3 represents the specification of the solar cell. Table 4 depicts the inference of fill factor and efficiency of coatings from 100 to 600 nm thickness placed on solar cell.

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## 3. Theoretical analyses on transient heat conduction in a single cell

### Case-1: Transient Heat Conduction in a Single Cell without $SnO_2$ coating

The motive of this work is to predict the heat loss due to convection to ambient air w.r.t to transient heating of solar cell without $SnO_2$coating. 3D geometry model is developed in CATIA without $SnO_2$ coating on solar cell.

### 3.1. Physical Model and Formulation of Single Cell without $SnO_2$ Coating

The geometric model Figure 1is a rectangular flat plate collector type solar cell placed in atmosphere. Initially the ambient temperature is $T_a$. SRI (heat flux) strikes the top surface of solar cell from 6:00 to 20:00(hrs). Due to increasing intensity of solar radiation the cell gets heated, among which a part of heat is lost due to natural convection laminar flow from all the six surfaces of the cell. The process of unsteady state heat conduction in the cell is governed by the following equation.

*Table4. Fill Factor and efficiency of single cell*

| Type | $P_{max}$ (mW) | $I_{SC} \times V_{OC}$ (mW) | FF % | η% |
|---|---|---|---|---|
| **Single Solar Cell** | 0.91 | 3.5 | 26 | 24.7 |
| **Single solar cell with $SnO_2$ coating 100nm** | 0.98 | 3 | 32 | 26.1 |
| **300nm** | 1.05 | 3.25 | 32 | 28.3 |
| **400nm** | 1.19 | 3.5 | 34 | 32.3 |
| **500nm** | 0.96 | 3 | 32 | 26.1 |
| **600nm** | 0.85 | 3 | 28 | 23 |

$$\rho c \frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right) \qquad (2)$$

*k* =thermal conductivity of solar cell.

*Figure 1. Geometric model of single cell without $SnO_2$ coating*

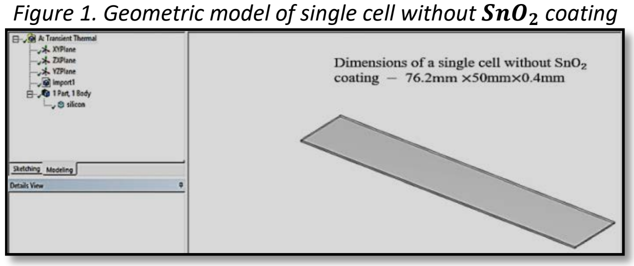
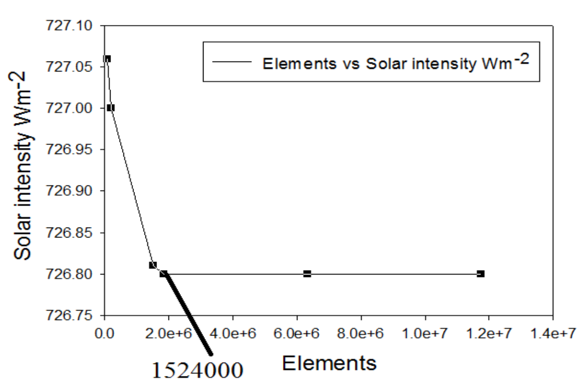



*Figure 2. Grid independence test of solar cell*




The mesh generation of single cell is done in ANSYS workbench. Hexahedral elements of fine size and patch conformation method are employed to create a good quality mesh. Figure 2 represents the gird independence test done for a single cell. Table 5 presents the material properties of single cell without coating.

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*Figure 3. Boundary conditions of single cell with SnO_2 coating*

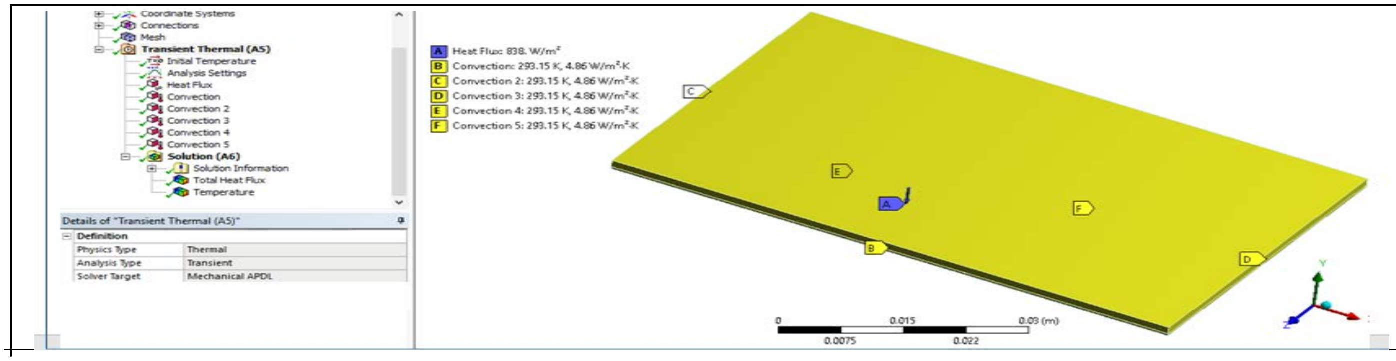


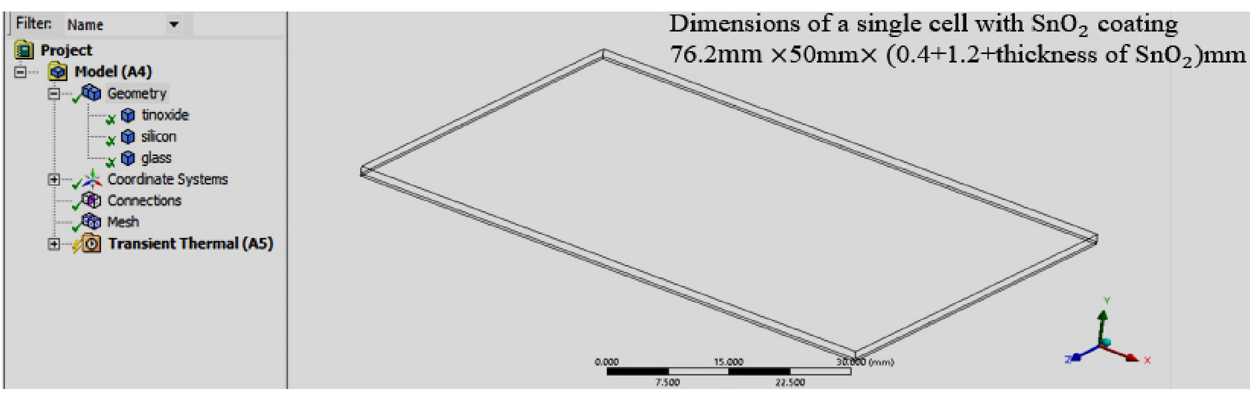

*Table 5. Material properties of single cell without coating*

| Material | Silicon | Tin oxide | Glass |
|---|---|---|---|
| Thermal conductivity ($\mathrm{Wm^{-1}.K^{-1}}$) | 131 | 0.6 | 2 |
| Specific heat ($\mathrm{Jkg^{-1}K^{-1}}$) | 677 | 733 | 600 |
| Density ($\mathrm{kgm^{-3}}$) | 2330 | 6950 | 1250 |
| $h_{eff}$ effective heat transfer coefficient at all walls ($\mathrm{Wmm^{-2}.K^{-1}}$) | 4.68 | 4.68 | 4.68 |
| Thickness mm | 0.4 | $1\times 10^{-3}$- $7\times 10^{-3}$ | 1.2 |

**Case-2: Transient Heat conduction in a Single Cell with Sn$O_2$ coating**

Figure 3 shows Physical Model and Formulation of Single Cell with SnO_2 CoatingSnO_2coating of 100nm to 600nm thickness is placed on solar cell as top surface and the variation in Q_out is absorbed. The 3D geometric model is generated in CATIA and imported into ANSYS is shown in Figure 4.

*Figure 4. Solar cell with coating*




## 4. Conclusion

An experimental method is demonstrated to apply nano coating of tin oxide film on solar cells for reducing reflection of heat. The tests conducted with the nano-coated solar cells showed that the cell efficiency has increased from 24% without coating to 31% with a nano-coating for400nm thickness of coating on the solar cell. The results of the theoretical analysis conducted on a single cell reveal a 2% saving in the heat loss from the cell with nano-coating compared to that without coating. As the coating thickness is increased from zero to 600nm the heat loss due to convection decreased monotonically from 461.4 to 452 W/m$^2$.Table 6 gives the overall comparison of heat loss due to convection with respect to hourly variation of solar cell with coating and without coating.

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*Table 6. Comparison of heat lost due to convection from case-1 and case-2*

| Time (hrs) | $Q_{in}\,(Wm^{-1}.k^{-1})$ | $Q_{out}\,(Wm^{-1}.k^{-1})$ Without coating | $Q_{out}\,(Wm^{-1}.k^{-1})$ With coating |
|---|---|---|---|
| 6:00 | 8 | 3.5 | 3.1 |
| 7:00 | 71 | 54 | 46.19 |
| 8:00 | 232 | 78.65 | 70.9 |
| 9:00 | 442 | 210.97 | 205.83 |
| 10:00 | 616 | 312.58 | 309.41 |
| 11:00 | 733 | 354.37 | 311.22 |
| 12:00 | 819 | 401.52 | 397.61 |
| 13:00 | 824 | 407.69 | 399.53 |
| 14:00 | 838 | 461.42 | 452.02 |
| 15:00 | 425 | 227.10 | 210.32 |
| 16:00 | 477 | 249.9 | 211.89 |
| 17:00 | 122 | 106.61 | 89.73 |
| 18:00 | 114 | 73.99 | 67.52 |
| 19:00 | 31 | 13.35 | 12.6 |
| 20:00 | 7 | 3.9 | 3.6 |

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