Sputtered Aluminum Doped Zinc Oxide Thin Films as TCO in Improving the Current Density (Jsc) for HIT Solar Cell

Nagesh M[1], Subramanyam T K[2]
[1]*Research Assistant, Electrical & Electronics*
Dept. R.V. College of Engineering, Bangalore, Karnataka,India-560059
[2]*Head, Interdisciplinary Research Centre, R.V. College of Engineering, Bangalore, KarnatakaIndia-560059*

Abstract: In this paper, Aluminum doped Zinc oxide (ZnO:Al) films were deposited on glass substrates by using dc magnetron sputtering technique with a maximum thickness of around 300nm. Aim is to improve optical and electrical characteristics of Heterojunction Intrinsic Thin (HIT) solar cells by employing thin ZnO:Al as window layer(TCO) as well as front contact. The optimized ZnO:Al films have shown a maximum average optical transmittance of 86% and band gap of 3.07eV for a layer thickness of 190nm on a glass substrate kept at a moderate temperature of 200oC. Simulation studies shows that the achieved results have been compared and correlated with that of the theoretical results. It is found that simulated results have more absorption at shorter wavelength due to ZnO:Al and it is agree well with the theory. Also due to ZnO:Al material, 25.761% increase in Ideal current density (Jsc) for our modeled solar cell device.
Keywords –ZnO:Al films, TCO, Sputtering, Simulation, Experimental, HIT Solar Cell

I. INTRODUCTION

Hetorojunction Intrinsic Thin (HIT) solar cells employs TCOs as a window layer in their designs. Transparent Conductive Oxides (TCO) films are having high electrical conductivity and optical low UV-IR absorption, which are crucial requirements as a window layer for any solar cell device. TCO layers act as optically transparent electrode that allows photons into the solar cell and transports the photo-generated electrons to the external device terminals. Usually, the TCO films are n-type semiconductors such as Indium Tin Oxide (ITO), Tin Oxide (SnO_2) and Zinc Oxide (ZnO), whereas ITO film is the one most used in these devices up to now. Recently, Al doped ZnO (ZnO:Al) film is one of the materials which could replace the ITO films. The direct optical band gap of ITO films is generally greater than 3.75 eV although a range of values from 3.5 to 4.06 eV have also been reported in the literature [1].

This research study uses ZnO:Al. It is widely used because the films have electrical and optical properties similar to those of ITO, and because it is stable in a hydrogen atmosphere. Thin ZnO films should be doped by aluminum, since it has been remarked that extrinsic donors due to the dopant atom are more stable than intrinsic donors due to the native defects [2]. Al-doped Zinc Oxide (ZnO:Al) film exhibits remarkable electrical conductivity, together with high charge carrier density and mobility [3]

Computer simulation is an important tool in the study of solar cells that enables their optimization in the absence of significant resources with respect to a number of parameters. This approach is employed herein to optimize fabrication parameters of a HIT solar cells and compare the obtained data with theoretical results.

This paper contains two sections, first section presents the simulation studies by modeling the ZnO:Al on the c-Si substrate to evaluate the performance of ZnO:Al as TCO layer on HIT Solar cell. Simulations results such Optical Studies including Transmission, Reflection & Absorption. Electrical Studies including calculation of ideal current density (Jsc) are discussed.

The second starting with Deposition of ZnO:Al on glass substrate by sputtering technique and its structural and optical results discussion.

II. SIMULATION STUDIES

Simulation studies have been carried out by using several sets of experimental parameters of the ZnO:Al films as an input data. After several iterations, the following model block diagram (Figure 1) has been designed using Lumerical FDTD Solution. The proposed simulation model is to optimize the ZnO:Al on the HIT Solar Cell for evaluating the performance as Transparent Conductive oxide on HIT Solar Cell.

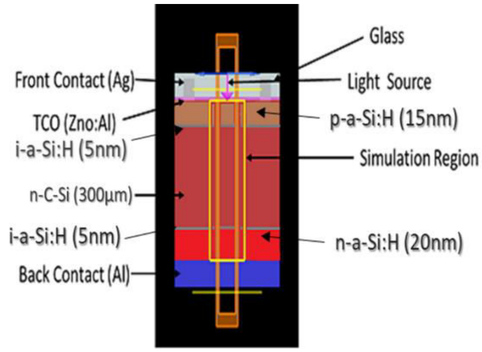

Figure 1: Simulation block diagram.

Wavelength (nm)	Refractive Index(n)	Extinction Coefficient (k)
300	2.15	0.17520
400	2.01	0.00123
500	1.89	0.00112
600	1.81	0.00239
700	1.75	0.00454
800	1.68	0.00830
900	1.62	0.01427

Table.1. Input Parameters for ZnO:Al for simulation [www.refractiveindex.info]

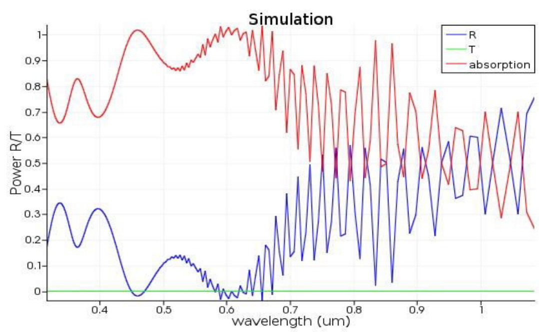

Figure 2: Simulated reflection, transmission and absorption of the C-Si Solar cell with TCO

To verify the above simulation results, Theoretical results are also calculated and shown in the Figure 2 along with simulation results. The Figure 3 shows that simulated results have more absorption at shorter wavelengths due to TCO and it is agree well with the theory.

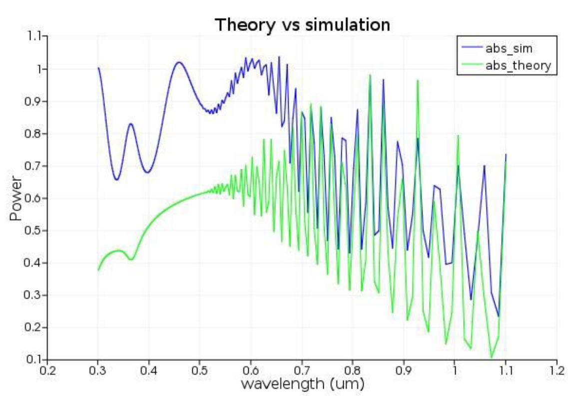

Figure 3: Theoretical reflection, transmission and absorption vs Simulated Results

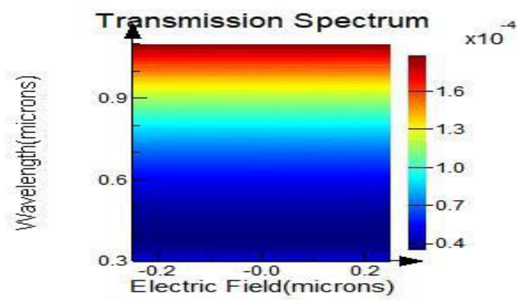

Figure 4: Optical generation rate of the selected simulated region

Figure 4 shows where the absorbed photons (electron-hole pairs) are concentrated in solar cell

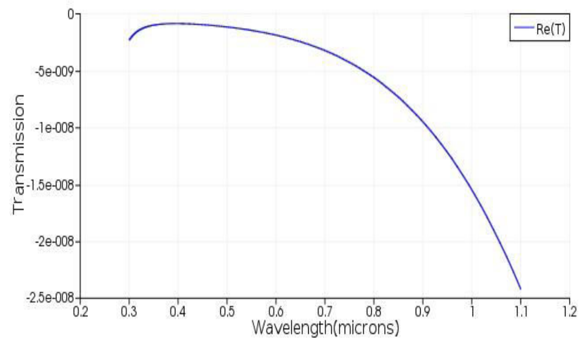

Figure 5: Line plot of the optical generation rate

Figure 5 shows absorption is high at the top surface of the silicon solar film and then drops exponentially as we move deep into the film. This decreases in the number of photo-generated electron-hole pair is due to the absorption of the optical signal as sunlight travels through the silicon film.

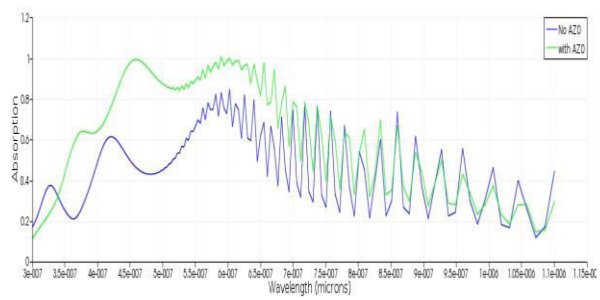

Figure 6: Effect of TCO coating on Solar cell

Figure 6 shows that the absorption is significantly improved at shorter wavelength region by adding TCO material on solar cell device.

We also calculated the Ideal short-circuit current density (Jsc) for with and without TCO layer. Jsc values are:
Jsc (without TCO) =203.714 A/m2
Jsc (with TCO) =274.405 A/m2
Results show that, due to TCO material 25.761% increase in Jsc for our modeled solar cell device.

III. EXPERIMENTAL SECTION:

Deposition then structural and optical results discussions

3.1 Deposition of ZnO:Al

Aluminum doped ZnO (ZnO:Al) films have been deposited by DC magnetron sputtering process using 5N pure zinc oxide target doped with 2 wt % of Al2O3 as a target by varying the process parameters such as substrate temperature, Target power and deposition time as shown in Table.2

Sample no.	Target Power (W)	Gas (sccm)	Temp(˚C)	Time (min)	Thickness (nm)
	150	63	200	80	278
	150	65	250	60	164
	150	62	200	40	172
	100	65	200	70	231
	100	70	150	60	117
	150	68	200	20	38
	150	69	200	20	86
	150	60	200	30	66
	150	70	200	25	92

Table.2.Process Parameters

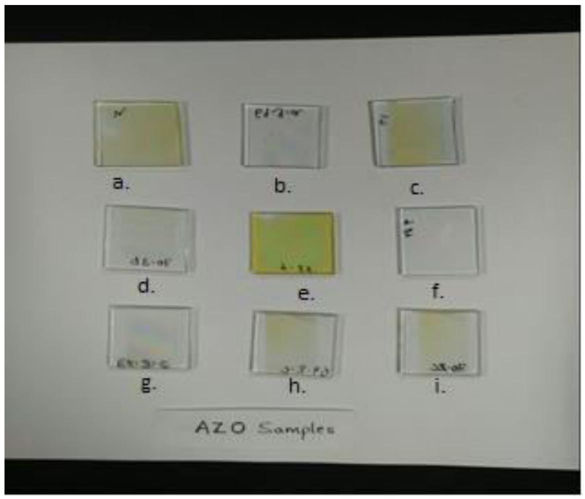

Figure 7: Deposited ZnO:Al.

The chamber was pumped down to 5.0 × 10-6 mbar and the process was carried out around 3.0x10-3mbar by varying the target power between 50-200W (dc). Figure 7 shows the image of the deposited films.

3.2 ZnO:Al Thickness measurements

The thickness of the deposited ZnO:Al films was measured using stylus profiler of Veeco-Dektak 6M model and the measured thickness of these deposited films was in the range 40-280 nm by changing deposition time. Dependence of thickness on the deposition time is shown in the Figure 8.

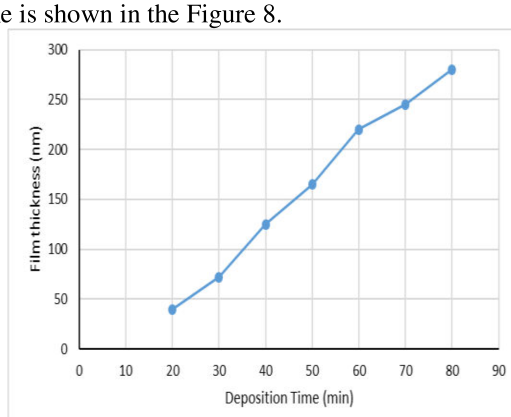

Figure 8: Thickness of the AZO films at different deposition time.

3.3 Structural characterization

The structural properties of the deposited ZnO:Al films were studied by using, a Shimadzu maxima-7000 X-ray diffractometer (XRD) in which Cu Kα radiation wavelength = 1.54182 Ao. Figure 9 shows the XRD image of the deposited film. The observed Major peaks at 2θ : 32.8, 34.3 and 35.1 deg represents 100, 002 and 101 planes respectively. Additionally, the intensity of the (002) peak is obviously stronger than other peaks, suggesting that ZnO:Al crystallites are highly oriented with c-axis being perpendicular to the substrate.

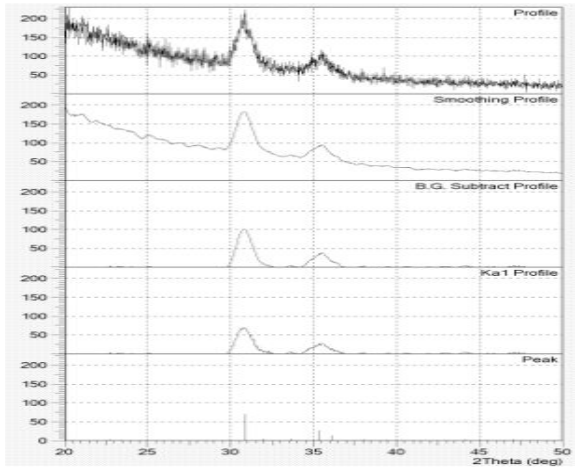

Figure 9: XRD image of ZnO:Al films

3.4 ZnO:Al Optical measurements

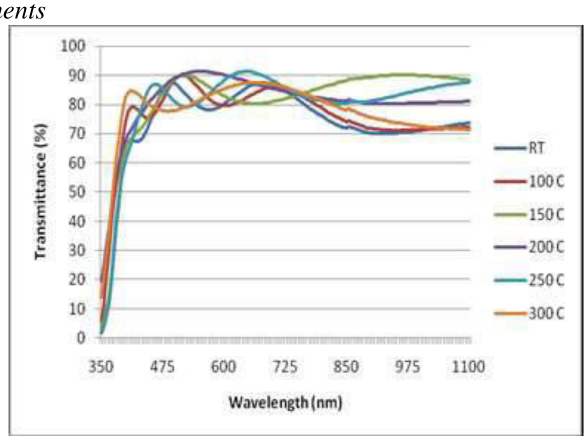

Figure 10: Optical transmittance spectra of ZnO:Al films

The optical transmittance spectra of the ZnO:Al films deposited at different substrate temperature is shown in the Figure 10. Optical measurements (reflectance and transmittance) in the spectral range from 350 nm - 1100 nm were carried out using UV-VIS spectrophotometer (Perkin Elmer Lambda 35). The spectrophotometer had two radiation sources; a deuterium lamp for UV range and a halogen lamp for visible (VIS) and near infrared (NIR) range. The films sputtered at a substrate temperature of 200ºC exhibited an average optical transmittance of 86%. The measured average transmittance of the films varied in the range of 79% - 86% and the optical band gap was determined using Tauc plot((α^2) vs hv)and it was in the range of 2.71 eV to 3.14 eV.

IV. CONCLUSION

Aluminum doped Zinc oxide films were deposited on glass substrates by using DC sputtering technique with the aim of optimizing thin window layer for HIT Solar cells. The XRD results reveals uniform deposition & high preferred orientation (002) of the ZnO:Al films. The measured thickness of the deposited films is in the range of 40nm to 280nm. The films sputtered at a substrate temperature of 200ºC exhibited an average optical transmittance of 86% and Bandgap of 3.14eV for a layer thickness of 190nm. By utilizing the above optimized experimental parameters & properties, Simulation studies were conducted to investigate and understand the effect of ZnO:Al as a window layer (TCO) on HIT solar cells. And the results have shown an enhanced optical absorption at shorter wavelength region which resulted with an increase in the Ideal short circuit current density(Jsc) of 25.761% for our modeled solar cell device.

V. ACKNOWLEDGEMENT

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