Alinteri J. of Agr. Sci. (2021) 36(1): 682-691
e-ISSN: 2587-2249
info@alinteridergisi.com

http://dergipark.gov.tr/alinterizbd
http://www.alinteridergisi.com/
DOI:10.47059/alinteri/V36I1/AJAS21096

RESEARCH ARTICLE

Simulation of Absorption Spectra and Comparing Efficiency of Glass and ZnO (Protective Layer) based Solar Cell for Green Energy

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ARTICLE INFO

Article History:
Received: 13.04.2021
Accepted: 17.05.2021
Available Online: 28.06.2021

Keywords:
Glass
Solar Cells
ZnO
Efficiency
Nanotechnology
Novel Material
Green Energy

ABSTRACT

Aim: Efficiency of Glass (protective layer) based solar cells and ZnO (protective layer) based solar cells was obtained by varying thickness (1000 nm to 6600 nm) of protective layer. **Materials and Methods:** Efficiency of Glass (protective layer) based solar cells (n = 57) was compared with ZnO (protective layer) based solar cells (n = 57) by varying thickness of protective layer ranging from 1000nm to 6600nm in the Nano hub Simulation environment. **Results:** ZnO (protective layer) based solar cell has significantly higher efficiency (21.17%) than Glass (protective layer) based solar cell (20.21%). **Conclusion:** Within the limits of this study, ZnO (protective layer) based solar cells offer better efficiency.

Please cite this paper as follows:

Rojasri, K. and Dr. Deepak, A. (2021). Simulation of Absorption Spectra and Comparing Efficiency of Glass and ZnO (Protective Layer) based Solar Cell for Green Energy. *Alinteri Journal of Agriculture Sciences, 36*(1): 682-691. doi: 10.47059/alinteri/V36I1/AJAS21096

Introduction

Comparative analysis of efficiency of glass (protective layer) based solar cell and ZnO (protective layer) based solar cell is investigated through simulation by varying thickness of protective layers. Yan guo et.al, proposed a method for designing highly efficient and stable ZnO based perovskite solar cells that provided an efficiency upto 14.25% (Guo et al. 2018). S. Sheehan et.al, concluded that high performance solar cells can be produced using FTO-coated willow glass (Sheehan et al. 2015). Noel Djongyang et.al, concluded that passive and active solar systems can be implemented for building-integrated energy systems (Djongyang, Tchinda, and Kapseu 2012). Mohd Rizwan Sirajuddin Shaik et.al, explored the applications of solar energy systems like electricity generation, heating and cooling of buildings in residence and industry (Shaikh 2017).

Several research articles were published on efficiency of Solar cells in the past 5 years.

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12 research articles were published in IEEE explore and 859 research articles were published in science direct. In this work the focus is on two types of Solar cells, Glass (protective layer) and ZnO (protective layer) based solar cell. Shruti Sharma et.al, explained that solar cells are the renewable source devices used for converting light energy to electrical energy based on the concept of photovoltaic effect. Mehreen Gul et.al, explained photovoltaic effect as the generation of a potential when radiation ionises the area or near the built-in theoretical semiconductor firewall(Gul, Kotak, and Muneer 2016) and are a great alternative for fossil fuels and petroleum deposits(S. Sharma, Jain, and Sharma 2015). Xinrui Wang et.al, has done research on implementation of photovoltaic power generation along with hydro power generation systems by conservation of energy in storage systems and proposed that encapsulation technology coupled with silicon helps to produce solar cells with higher stability(D. Wang et al. 2016). S.Gall et.al proposed ZnO-Al coated glass which can be used for preparing poly-Si thin film

solar cells (Gall et al. 2009). S.Saeful Bahri et.al, developed a public transportation system using two technologies namely network-connected systems and autonomous systems (Bahri and Purwantiasning 2019)(X. Wang, He, and Ju 2015). S. Seong Il Cho et.al developed thin-film silicon PV modules based on tandem solar cells with amorphous silicon as top cell and micro crystalline silicon as bottom cell used for lowering manufacturing costs (Cho et al. 2019). Cham thi trinh et.al, concluded that efficiency of solar cells can be increased by improving surface passivation and bulk quality using cell fabrication process in solar cells(Trinh et al. 2018). Masoud Abrari et.al, showed that composite nanostructures can be synthesised using dual anodic dissolution technique which resulted in increased efficiency of ZnO based Dye-Synthesized Solar Cells (DSSCs) (Abrari et al. 2019).

Previously our team has a rich experience in working on various research projects across multiple disciplines (Sathish and Karthick 2020; Varghese, Ramesh, and Veeraiyan 2019; S. R. Samuel, Acharya, and Rao 2020; Venu, Raju, and Subramani 2019; M. S. Samuel et al. 2019; Venu, Subramani, and Raju 2019; Mehta et al. 2019; P. Sharma et al. 2019; Malli Sureshbabu et al. 2019; Krishnaswamy et al. 2020; Muthukrishnan et al. 2020; Gheena and Ezhilarasan 2019; Vignesh et al. 2019; Ke et al. 2019; Vijayakumar Jain et al. 2019; Jose, Ajitha, and Subbaiyan 2020). Now the growing trend in this area motivated us to pursue this project.

Inadequate efficiency of solar cells is a major challenge which needs to be addressed in order to meet the increasing demand of electricity. Ahmed Suhail et.al, designed a method for improving efficiency of graphene/Si schottky junction solar cells using DUV treatment(Suhail et al. 2018). Efficiency of Glass (protective layer) based solar cells and ZnO (protective layer) based solar cells are compared by varying protective layer thickness from 1000nm to 6600nm in order to optimize it.

Materials and Methods

In this research work there are two groups. Group 1 refers to glass (protective layer) based solar cells and group 2 refers to ZnO (protective layer) based solar cells(Praveen and Vijaya Ramaraju 2017). The pre-test analysis was done using clincalc.com by keeping gpower at 80%, threshold at 0.05%, confidence interval at 95%("High Efficiency Silicon Solar Cells" 2013)(Zhao et al. 2019). Sample size of each group is 57 and the total sample size is 114. Nanohub© Simulation tool is the open and free platform for computational research, teaching, and cooperation in nanotechnology and materials science.

In sample preparation of group 1, efficiency of Glass (protective layer) based solar cells were simulated for different thickness of protective layer from 1000nm to 6600nm. Initially open Nanohub simulation tool. Select Resources and choose Tools. From Tags select Solar Cell Modelling and Simulation. After that in Resources, Photovoltaics QCRF-FDTD Simulator tool has to be selected and launched. Simulation window appears, now in simulation options select the protective layer and choose glass material. Measure efficiency by varying thickness of glass (protective layer).

In sample preparation of group 2, process is carried out as in the above preparation. In simulation options, select ZnO material protective layer instead of glass material and measure efficiency by varying thickness of ZnO (protective layer).

Nanohub© simulation tool is used for simulating efficiency graphs and ORIGIN PRO $V_{8.0}$ software and SPSS Softwares are used for comparative analysis of efficiency of Glass (protective layer) based solar cell and ZnO(protective layer) based solar cells. Protective layer thickness is the independent variable and efficiency is the dependent variable as it depends upon thickness.

Results

Measurements of efficiency were performed for different thickness of protective layer (Glass, ZnO) based solar cells. Efficiency of Glass(protective layer) based solar cells for Single junction PV cell and Tandem PV cell are tabulated (Table 1). Single junction PV cell based glass(protective layer) solar cells appear to have higher efficiency compared to tandem PV cell based glass(protective layer) solar cells due to higher current mismatching, open circuit current density of tandem PV cell (Meillaud et al. 2006) (Fig 1). Efficiency of ZnO(protective layer) based solar cells for Single junction PV cell and Tandem PV cell are tabulated (Table 2). Single junction PV cell based ZnO(protective layer) solar cells appear to have higher efficiency compared to Tandem PV cell based ZnO(protective layer) solar cells (Fig 2). Single junction PV cell based ZnO(protective layer) solar cells have higher efficiency compared to single junction PV cell based glass(protective layer) solar cells (Fig 3). Efficiency of tandem PV cell based ZnO solar cells is higher compared to tandem PV cell based glass solar cells (Fig 4). Independent T test analysis between efficiency of glass(protective layer) and ZnO (protective layer) based solar cells using SPSS software are tabulated (Table 3).

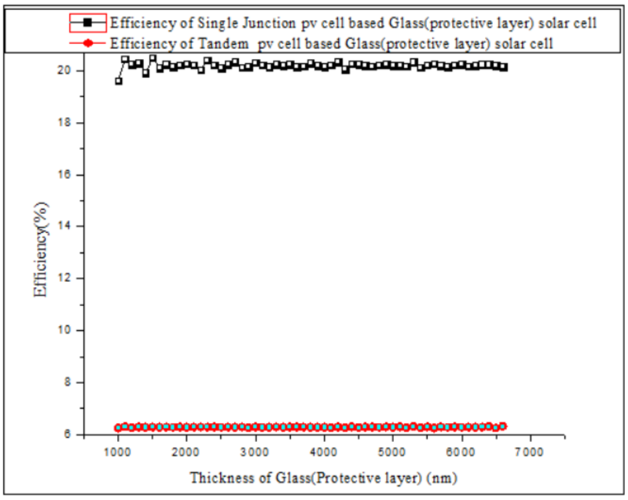

Fig.1. Comparison of efficiency for different PV cells in glass(Protective layer) based solar cell. Efficiency is measured for varying protective layer thickness from 1000nm to 6600nm. **Black** line represents efficiency of single junction PV cell and **red** line represents efficiency of tandem PV cell. Single junction PV cells appear to have higher efficiency than tandem PV cell glass(protective layer) based solar cells.

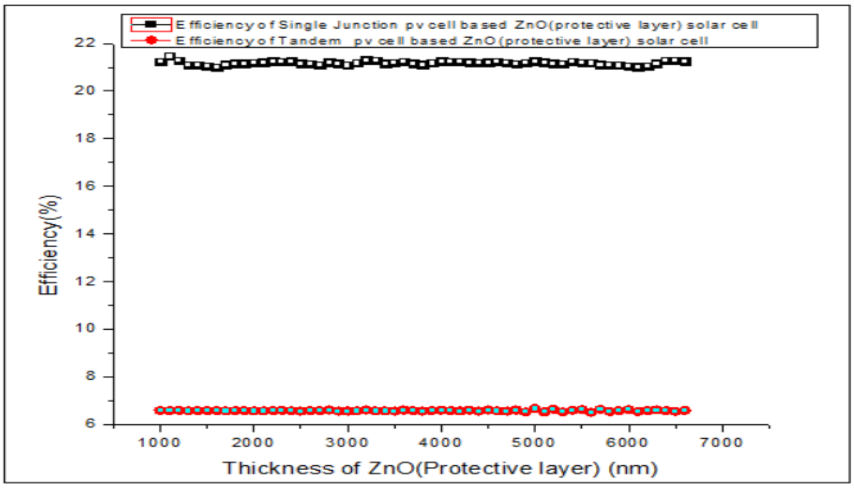

Fig.2. Comparison of efficiency for different PV cells in ZnO (protective layer) based solar cells. Efficiency is measured for varying protective layer thickness from 1000nm to 6600nm. **Black** line represents efficiency of single junction PV cell and **red** line represents efficiency of tandem PV cell. Single junction PV cell appears to have higher efficiency than tandem PV cell based ZnO (protective layer) based solar cell.

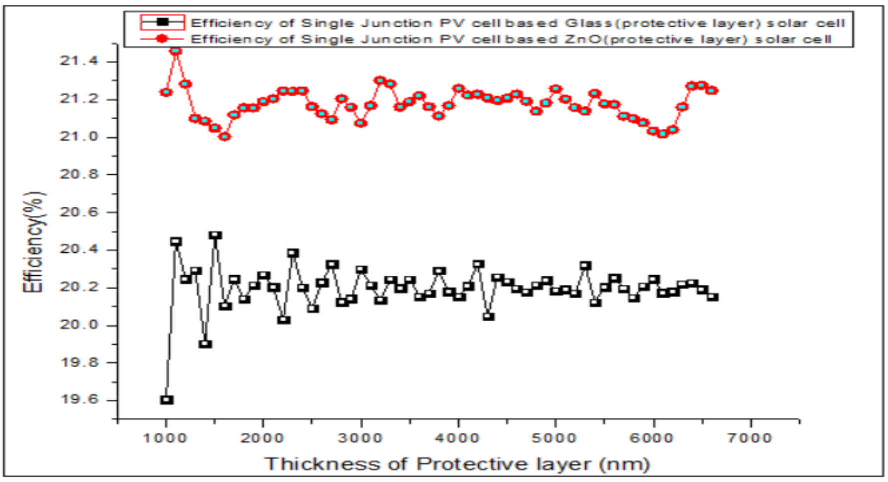

Fig.3. Comparison of efficiency of single junction PV cell based glass (protective layer) solar cell that is represented by **black** line and single junction PV cell based ZnO (protective layer) solar cell that is represented by **red** line.

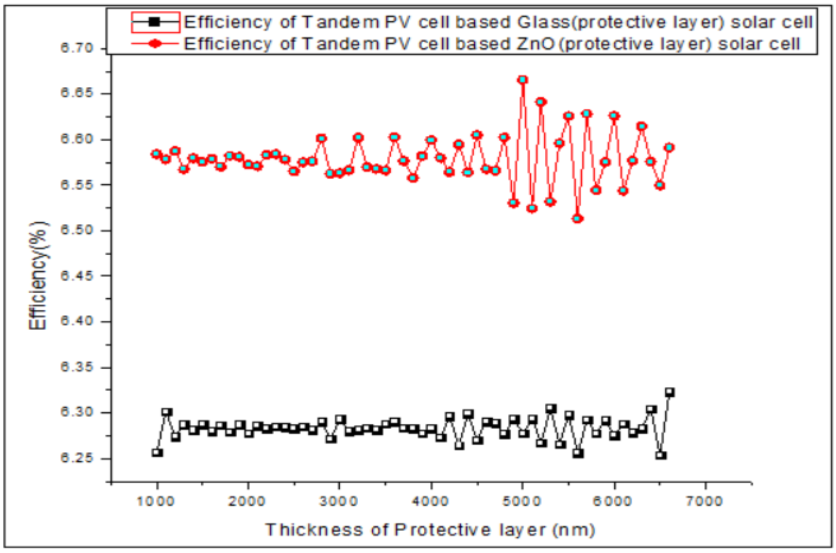

Fig.4. Comparison of efficiency of tandem PV cell based glass(protective layer) solar cell that is represented by **black** line and tandem PV cell based ZnO(protective layer) solar cell that is represented by **red** line. Efficiency of tandem PV cell based ZnO solar cells is higher compared to PV cell based glass solar cells.

Table 1. Efficiency for varying thickness of glass (protective layer) solar cell.

THICKNESS(nm)	Efficiency(%) by using Single junction PV cell based Solar Cell	Efficiency(%) by using Tandem photovoltaics PV cell based Solar Cell
1000	19.6057	6.25716
1100	20.448	6.3013
1200	20.2468	6.27432
1300	20.2915	6.28716
1400	19.9023	6.28101
1500	20.4815	6.28762
1600	20.1023	6.27968
1700	20.2458	6.28685
1800	20.1384	6.27935
1900	20.2124	6.28705
2000	20.2669	6.27773
2100	20.2023	6.28583
2200	20.0303	6.28327
2300	20.3877	6.28556
2400	20.2017	6.28488
2500	20.0892	6.28269
2600	20.2281	6.28526
2700	20.3253	6.28139
2800	20.1228	6.29081
2900	20.1416	6.27196
3000	20.2986	6.29299
3100	20.2123	6.28022
3200	20.1336	6.28187
3300	20.2426	6.28364
3400	20.1968	6.28196
3500	20.2448	6.28834
3600	20.1531	6.29033
3700	20.1693	6.28354
3800	20.2905	6.28288
3900	20.1785	6.277555
4000	20.1517	6.28289
4100	20.2101	6.2733
4200	20.3263	6.29626
4300	20.0468	6.26473
4400	20.2544	6.29915
4500	20.2317	6.27049
4600	20.1958	6.29076
4700	20.1753	6.28883
4800	20.2124	6.27682
4900	20.2395	6.29315
5000	20.1839	6.27761
5100	20.1908	6.29395
5200	20.1703	6.26724
5300	20.3186	6.30529
5400	20.1224	6.26589
5500	20.2038	6.29789
5600	20.2529	6.25617
5700	20.1959	6.29281
5800	20.1442	6.27752
5900	20.206	6.29233
6000	20.2461	6.27549
6100	20.1733	6.28822
6200	20.1794	6.27909
6300	20.2207	6.28319
6400	20.2261	6.30473
6500	20.1912	6.25375
6600	20.1528	6.32287

Table 2. Efficiency for varying thickness of ZnO(Protective layer) solar cell

Thickness(nm)	Efficiency(%) by using Single junction PV cell based Solar Cell	Efficiency(%) by using Tandem photovoltaics PVcell based Solar Cell
1000	21.2382	6.58383
1100	21.4563	6.57809
1200	21.282	6.58755
1300	21.1001	6.56721
1400	21.083	6.57924
1500	21.047	6.57533
1600	21.0022	6.57874
1700	21.1183	6.57017
1800	21.1548	6.58212
1900	21.155	6.58088
2000	21.1881	6.57273
2100	21.2042	6.57072
2200	21.2452	6.58302
2300	21.2429	6.584071
2400	21.2457	6.5779
2500	21.1621	6.56502
2600	21.1245	6.57497
2700	21.0921	6.57614
2800	21.2036	6.60126
2900	21.1571	6.56251
3000	21.0735	6.56312
3100	21.1672	6.56645
3200	21.3026	6.60197
3300	21.2822	6.56966
3400	21.1598	6.56789
3500	21.188	6.56587
3600	21.2207	6.60249
3700	21.162	6.57651
3800	21.1132	6.5581
3900	21.166	6.58166
4000	21.2578	6.59931
4100	21.2228	6.57952
4200	21.2277	6.56432
4300	21.2072	6.59462
4400	21.1943	6.56409
4500	21.2066	6.60486
4600	21.2285	6.56751
4700	21.1902	6.5657
4800	21.1372	6.60239
4900	21.1806	6.53048
5000	21.2558	6.66549
5100	21.2016	6.52437
5200	21.1559	6.64116
5300	21.1373	6.53152
5400	21.2313	6.59576
5500	21.1766	6.62547
5600	21.174	6.51315
5700	21.1111	6.62815
5800	21.0976	6.54455
5900	21.0764	6.57523
6000	21.0322	6.6258
6100	21.0164	6.54383
6200	21.0385	6.57685
6300	21.161	6.61457
6400	21.2709	6.57545
6500	21.2744	6.54954
6600	21.2471	6.59089

Table 3. T test comparison of efficiency of glass(protective layer) and ZnO(protective layer) based solar cells by varying thickness ranging from 1000nm to 6600nm. Statistically significant difference in efficiency of glass(protective layer) based solar cell and ZnO(protective layer) based solar cell is observed. ZnO(Protective layer) based solar cell appears to have the highest mean efficiency of single junction PV cell(21.176291) over glass(protective layer) based solar cell that has the lowest mean efficiency of single junction PV cell (20.215349). Mean efficiency of tandem PV cell based ZnO(protective layer) based solar cell(6.578944) appears to be higher than efficiency of tandem PV cell based ZnO(protective layer)(6.288858).

	Group	N	Mean	Std. Deviation	Std. Error Mean
Thickness	Glass	57	3800.00	1659.819	219.848
	ZnO	57	3800.00	1659.819	219.848
Efficiency of Single PV cell	Glass	57	20.215349	.1845463	.0244437
	ZnO	57	21.176291	.0812099	.0107565
Efficiency of Tandem PV cell	Glass	57	6.288858	.0408024	.0054044
	ZnO	57	6.578944	.0272129	.0036044

Table 4. Standard deviation for efficiency of single junction PV cell and efficiency of tandem PV cell based glass (protective layer) and ZnO (protective layer) solar cells are shown. There is a significant difference between the two groups since p<0.05 (Independent Sample T Test).

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	dfdfdf	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Thickness	**Equal variances assumed**	.000	1.000	.000	112	1.000	.000	310.913	-616.034	616.034
	Equal variances not assumed			.000	112.000	1.000	.000	310.913	-616.034	616.034
Efficiency of Single PV cell	**Equal variances assumed**	1.780	.185	-35.983	112	.000	-.9609421	.0267058	-1.0138562	-.9080280
	Equal variances not assumed			-35.983	76.904	.000	-.9609421	.0267058	-1.0141212	-.9077630
Efficiency of Tandem PV cell	**Equal variances assumed**	.562	.455	-44.655	112	.000	-.2900857	.0064961	-.3029569	-.2772145
	Equal variances not assumed			-44.655	97.590	.000	-.2900857	.0064961	-.3029777	-.2771937

Significant difference in efficiency of glass(protective layer) based solar cells and ZnO(protective layer) based solar cells is observed. Single junction PV cell based ZnO(protective layer) solar cells have the highest mean efficiency(21.176291) over single junction PV cell based glass(protective layer) solar cells which have the lowest mean efficiency(20.215349). Tandem PV Cell based ZnO(protective layer) solar cell(6.578944) appears to give better mean efficiency than tandem PV cell based glass(protective layer) solar cell(6.288858). Standard deviation for efficiency of single junction PV cell and tandem PV cell of glass(protective layer) based solar cell and ZnO(protective layer) based solar cell are tabulated (Table 4). It can be seen that there is a significant difference between the two groups since p<0.05(Independent Sample T Test). Single junction PV cell based ZnO(protective layer) solar cells show higher efficiency compared to single junction PV cell based glass(protective layer) solar cells and tandem PV cell based ZnO(protective layer) solar cells show better efficiency compared to tandem PV cell based glass(protective layer) solar cells (Fig 5).

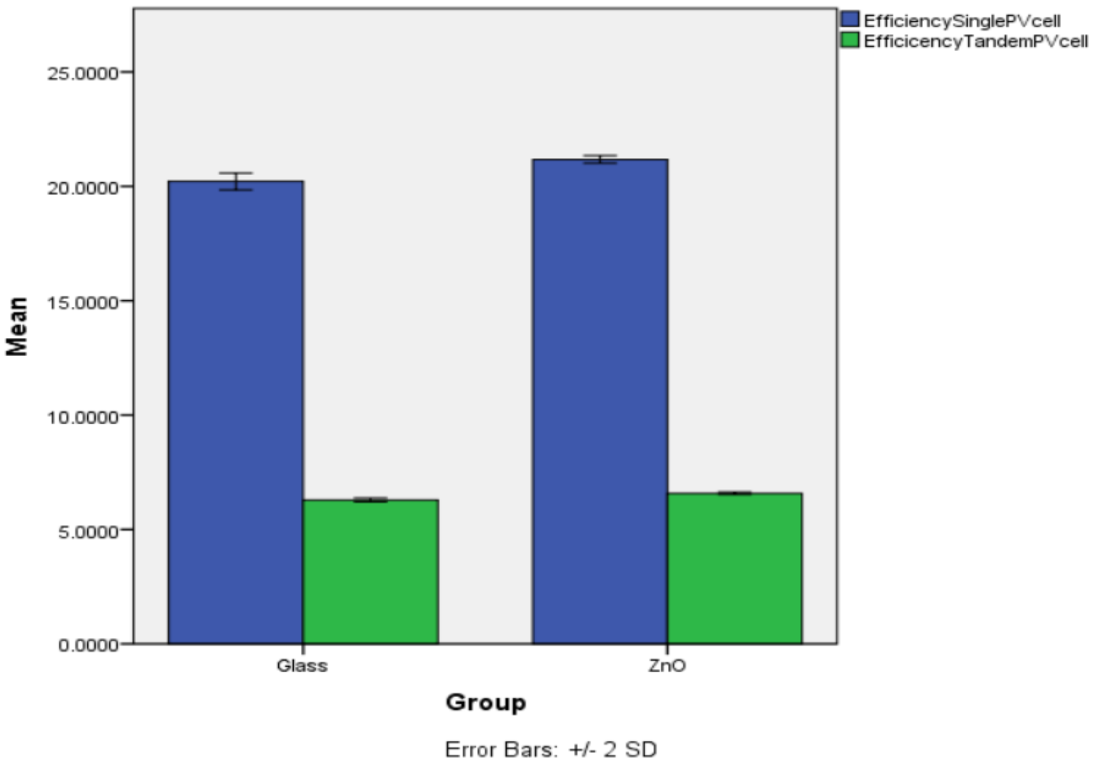

Fig. 5. The Bar chart compares mean (+/-2 SD) efficiency of single junction PV cell and efficiency of tandem PV cell of Glass (protective layer) based solar cell and ZnO (protective layer) based solar cell by varying thickness. There is a significant difference between the two groups as $p<<0.05$ (Independent Sample T Test). X Axis: Glass vs ZnO. Y Axis: Mean efficiency of Single PV cell and TandemPV cell.

Discussion

Comparison of efficiency of Glass(protective layer) based solar cells and ZnO(protective layer) is investigated in the present research work. Protective layer thickness is increased from 1000nm to 6600nm. In Glass(protective layer) based solar cells, efficiency of single junction PV cell increases from 19.6057 to 20.1528 and efficiency of tandem PV cell increases from 6.25716 to 6.32287. In ZnO(protective layer) based solar cells efficiency of single junction PV cell increases from 21.2382 to 21.2471 and efficiency of tandem PV cell increases from 6.58383 to 6.59089.

Fukran Dincer et.al explored on different factors affecting the efficiency of solar cells and those factors are cell temperature, energy conversion efficiency, shading, protective layer thickness, anti reflection layer thickness and active material thickness(Dincer and Meral 2010). Avijit Saha et.al, suggested in their work that non-uniform shading caused by the building model must be avoided for getting higher efficiency (Saha, Nipu, and Khan 2019). M.Senthilkumar et.al, concluded that efficiency increases with decrease in temperature("Effect of Temperature on Solar Photovoltaic Panel Efficiency" 2019).

Our institution is passionate about high quality evidence based research and has excelled in various fields ((Vijayashree Priyadharsini 2019; Ezhilarasan, Apoorva, and Ashok Vardhan 2019; Ramesh et al. 2018; Mathew et al. 2020; Sridharan et al. 2019; Pc, Marimuthu, and Devadoss 2018; Ramadurai et al. 2019). We hope this study adds to this rich legacy.

Shading and cell temperature does not affect our research work as this work is only limited to simulation. Ramadhani Bakari et.al, investigated the effect of Glass material thickness on efficiency and found that thickness of 4mm increases performance of air solar collectors by 7.6%(Bakari, Minja, and Njau 2014). M.Giannouli et.al, investigated morphology and its effects and discovered that presence of ZnO nanoparticles decreases efficiency of solar cells(Giannouli and Spiliopoulou 2012). After analysing the simulation results, observation is that thickness of protective layer affects the efficiency of solar cell. Thickness of the antireflection layer and active material of the solar cell also affect the efficiency of the solar cells. Precautions are taken to keep the thickness of both antireflection layer and active layer constant throughout the research work.

Solar cells designed were not tested at different ambient environments is one of the major limitations in the research work. In the future ZnO(protective layer) based novel solar cells can be designed for residential and commercial applications.

Conclusion

ZnO (protective layer) based solar cells give better efficiency compared to Glass(protective layer) based solar cells. Efficiency of single junction PV cell based ZnO (protective layer) solar cell is higher compared to efficiency of single junction PV Cell based Glass(protective layer) solar cell. Tandem PV cell based ZnO (protective layer) solar cells show better efficiency compared to tandem PV cell based glass (protective layer) solar cells.

Declarations

Conflict of Interests

No conflict of interest in this manuscript.

Author Contribution

Author K. Rojasri was involved in data collection, data analysis, manuscript writing. Author Dr. A. Deepak was involved in conceptualization, guidance and critical review of manuscript.

Acknowledgements

All the simulations used in this research paper were carried out in NanoHub and the data was processed in the tool and graphs were generated. The authors would like to express their gratitude towards Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences (Formerly known as Saveetha University) for providing the necessary infrastructure to carry out this work successfully.

Funding

We thank the following organizations for providing financial support that enabled us to complete the study.

1. Manac Infotech Pvt. Ltd.,
2. Saveetha university.
3. Saveetha Institute of Medical and Technical Sciences.
4. Saveetha School of Engineering

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