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優勝作品專輯

作品編號　100040

參展科別　工程學

作品名稱　Fabrication of Highly Efficient and Cost-effective Tandem Dye-sensitized Solar Cells for Building Integrated Photovoltaics

得獎獎項　二等獎

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關鍵詞

SECTION 1: INTRODUCTION

In recent years, there has been an extreme rise in population and economic development, which requires a great demand for energy worldwide. Global energy consumption has been increasing nearly every year for over half a century [1]; it is rapidly rising in the form of nonrenewable energy, such as coal, oil, natural gas, and fossil fuel. Fossil fuel overreliance has resulted in a dramatic rise in atmospheric carbon dioxide (CO_2) concentrations.

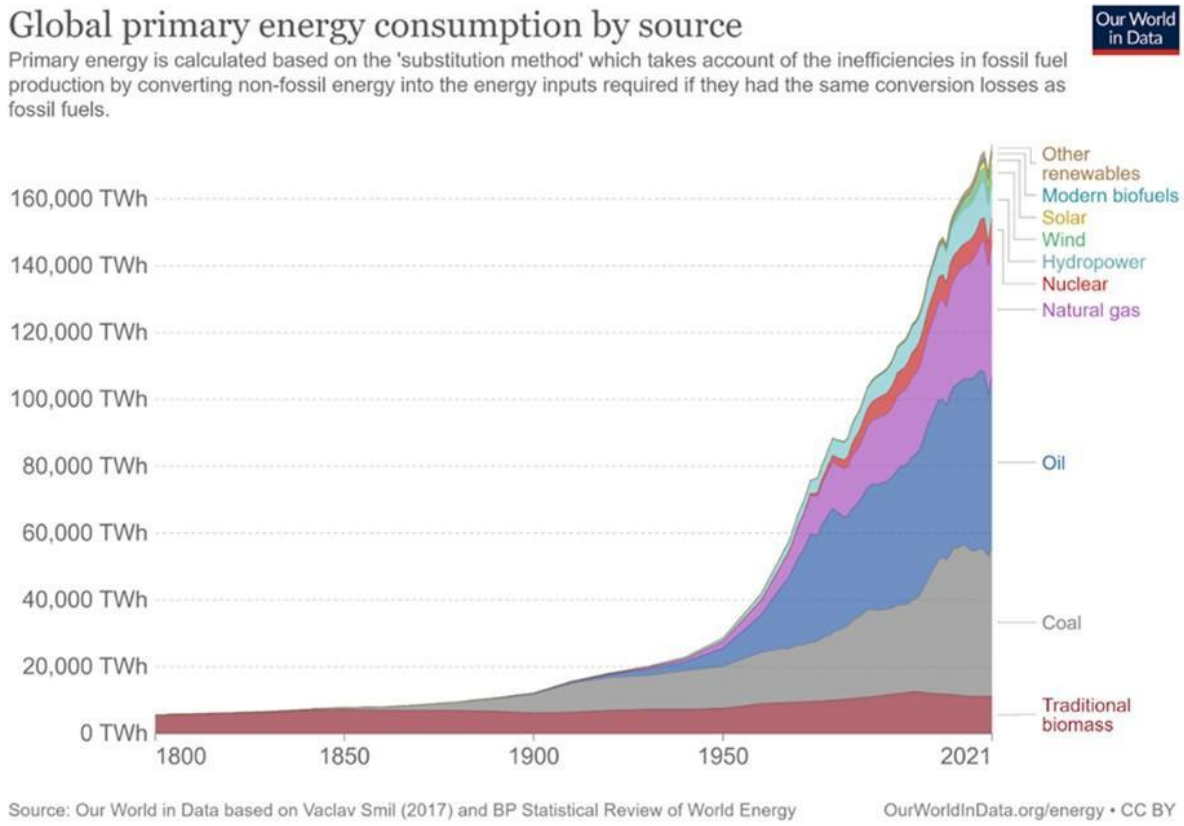


Figure 1. Global energy consumption by source. Our World in Data [1]

CO_2 levels at NOAA's Mauna Loa Atmospheric Baseline Observatory peaked in May at 421 parts per million for 2022, sending the atmosphere into territory not seen for millions of years [2]. CO_2 emissions contribute to climate change and global warming, resulting in severe environmental conditions [3].

The harsh impacts of CO2 caused by non-renewable energy sources have inspired the scientific community to find sustainable alternative energy sources. The sun provides much more energy than humans need to power everything on Earth [4], which is why solar energy is a convenient alternative to non-renewable energy sources. Solar energy is a great sustainable energy source because of its availability, simplicity of making, cheap cost, lifelong span, and it emits no greenhouse gases [5]. Solar energy is the conversion of energy from sunlight to electricity, and the conversion process may be converted directly or indirectly. Photovoltaic cells or solar cells are one of the ways to convert energy from sunlight to electricity directly.

Solar cells are a very efficient and easy way to harvest energy. In 1883, American inventor Charles Fritts made the first solar cells from selenium [6]. The first generation of solar cells was produced on silicon wafers using monocrystalline or polycrystalline silicon crystals. These silicon solar cells are inconvenient because they use lots of space, are hard to fabricate, and are expensive to store [7].

Third-generation solar cells, such as organic solar cells, perovskite solar cells (PSC), dye-sensitized solar cells (DSSC), and polymer-heterojunction solar cells, make a good substitute for first-generation solar cells. Third-generation solar cells have been widely researched due to their outstanding results, simplicity of fabrication, and low cost compared to first-generation solar cells [8].

Dye-sensitized solar cells:

One of the most promising thin films is Dye-sensitized solar cells, which were first discovered in 1991 by Michael Grätzel. DSSCs can turn visible light into electricity and are the only photovoltaic technology that mimics plants' photosynthesis [9]. It is the closest h]humanity has come to photosynthesis, making them fascinating devices; however, DSSC suffers from its low efficiency. DSSC is a photoelectrochemical cell where it has a sandwich-like structure. As it is shown in [figure 2], the cells consist of the glass substrate, a transparent conductive oxide (TCO) which is commonly fluorine tin oxide (FTO) or indium tin oxide (ITO), a Working electrode using nanostructured semiconductors such as titanium dioxide (TiO2), Dye molecules such as Ruthenium-based N719 or natural-based dye like blackberries, an electrolyte such as iodine/triiodide (I^-/I_3^-), a counter electrode which can be a catalytic material such as platinum(Pt), and then again TCO and a glass substrate.

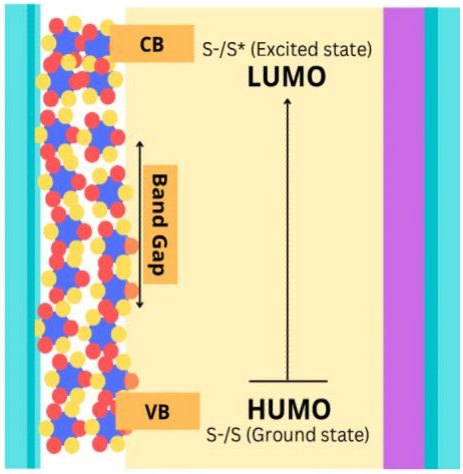


Figure 2. shows DSSC's structure

Perovskite Oxides:

Perovskite Oxides structure [10] follows the formula ABO3, where A is the larger cation and B is the smaller cation. In this structure, the B cation is 6-fold coordinated, and the A cation is 12-fold coordinated with the oxygen anions. Perovskite oxides exhibit attractive physical and chemical characteristics such as electronic conductivity and electrically active structure. In this study, perovskite oxide barium stannate was used.

Tandem Solar Cells:

One way to exceed the efficiency of single-junction solar cells is by multi-junction solar cells or tandem solar cells [11], which mixes p-n junction cells to achieve higher efficiency. Tandem solar cells are applied in this study to enhance the efficiency of DSSCs.

Energy Storage:

By 2050, solar will become the number one source of energy [12]. So, in the future the world is going to occupy a massive amount of solar energy. Hence, the most accessible and convenient option is to store this energy to utilize it effectively. Lithium-ion batteries and supercapacitors are prevalent due to their efficient performance as energy storage devices. However, lithium-ion batteries are costly, scarce, and very complex to work with, making supercapacitors (SCs) an ideal storage device to store solar energy due to their superior cycle life, high power density, and faster charge/discharge rates [13].

Barium Stannate (BaSnO3):

In DSSCs, a significant problem is their limited PCE. One of the ways to enhance the efficiency of DSSC is to incorporate the DSSC device in a tandem solar cell. TiO2 is a photoanode in DSSC and has a PCE of 4-5%, making it a very efficiency-limited material, so it is critical to find a way to enhance the PCE of DSSCs. Barium stannate or BaSnO3 (BSO) is a perovskite oxide material following the formula ABO3. BSO is a compatible and efficient material to use as a photoanode in DSSC and fabricate a tandem solar cell with it since it has a high PCE range and fast dye loading time.

Cosensitization:

Cosensitization is a very promising method to optimize the performance of DSSCs since it combines two or more dyes to cover more of the solar light spectrum. Ruthenium-based dye or N719, is the most commonly known and used dye. However, this N179 has a limited absorbance range within the solar light spectrum, and herein comes the role of Z709 dye. Z709 is found to be a great dye when it acts as a cosensitization along with N719[5].

Research problem:

DSSCs have a significant disadvantage: their low power conversion efficiency (PCE= η) due to electron loss when electrons are carried in the cell.

$$\eta = \frac{I_{sc} \times FF \times V_{oc}}{P_{in}}$$

Project's aim and objectives:

This project aims to enhance the efficiency of DSSC by fabricating a tandem solar cell by joining pristine TiO_2-based DSSC and BSO-based DSSC to make full use of the incident light and enhance the photovoltaic performance. For further optimization of the solar cell device, cosensitization method is applied to enable the dye material to be more flexible in absorbing the light under different ranges of the solar light spectrum.

Objectives:

- Synthesis of Barium stannate (BSO) for usage as a photoanode
- Characterization of BSO and titanium dioxide (TiO_2)
- Fabrication of two DSSCs. One cell TiO_2 based and the other is based on the synthesized BSO

- Measurement of each cell individually using a solar simulator
- Combining both cells to form a tandem solar cell
- Use Z709 as cosensitizer with N719

Novelty:

This project introduces a novel design of tandem solar cells that enhances the efficiency of Dye Sensitized solar cells by joining pristine TiO2-based DSSC with a BaSnO3-based DSSC which will achieve promising and outstanding results.

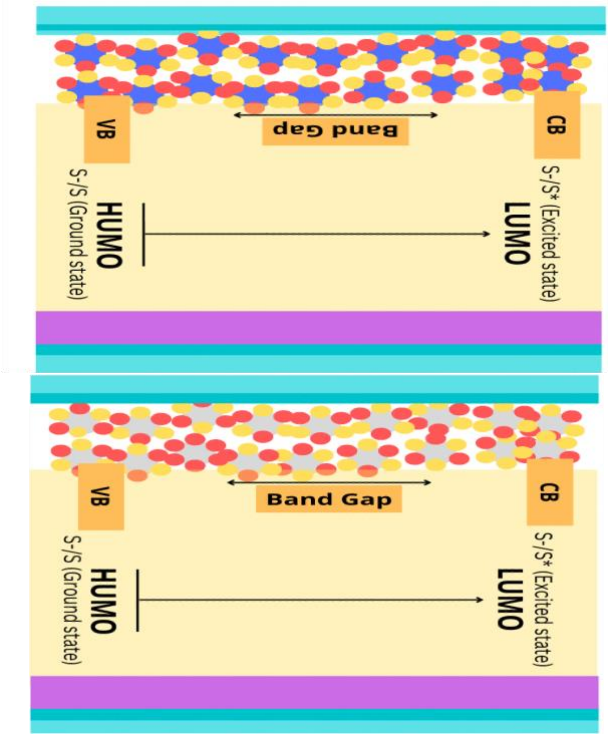


Figure 3. The novel structure of the DSSC tandem solar cell applied in this project.

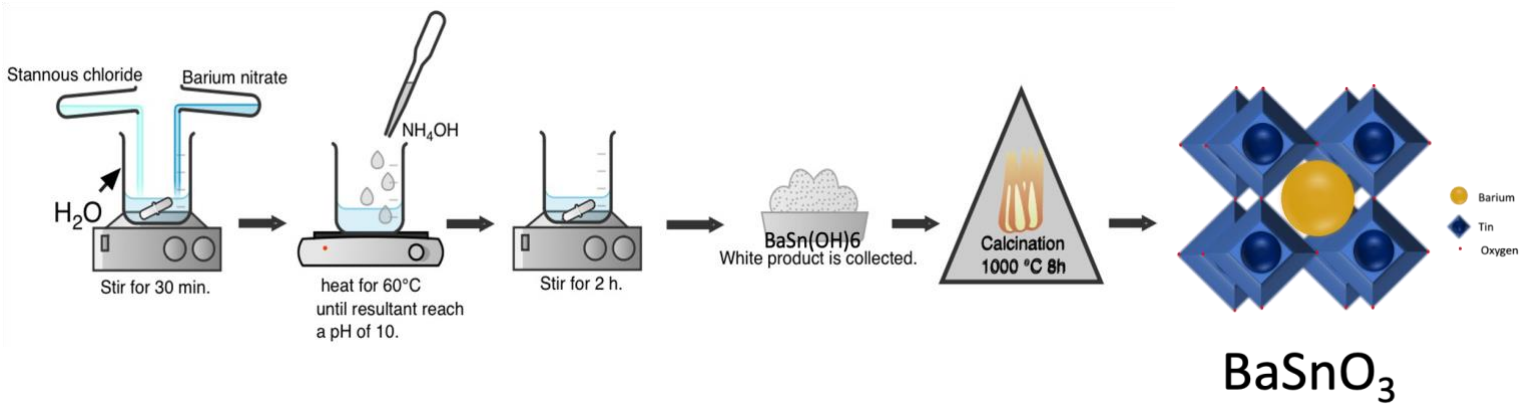
SECTION 2: METHODOLOGY

Materials:

Titanium dioxide paste, Platinum, and iodine-based electrolyte commercially bought from (Solaronix), ethanol (Sigma Aldrich), Barium nitrate (Sigma Aldrich), stannous chloride (Sigma Aldrich), Ammonium hydroxide (Sigma Aldrich), distilled water, ethyl cellulose (Sigma Aldrich), Glue, and terpinol.

Synthesis of $BaSnO_3$:

$BaSnO_3$ (BSO) nanoparticles were prepared by, in short, 10 mM each of $Ba(NO_3)_2$ and $SnCl_4$ were thoroughly stirred under 30% distilled water for 30 min to form a homogeneous solution. A 25% NH_4OH solution was added dropwise to the mixed solution until the pH of the resultant solution reached 10. The solution was centrifuged at 10,000 rpm for 2h, and a white product was collected. The product was dried at room temperature and further calcined at 1000 °C for 8 h to produce the $BaSnO_3$ phase. Then the obtained powder was allowed to make a paste using ethyl cellulose and terpinol.



Fabrication of the $BaSnO_3$-based DSSCs:

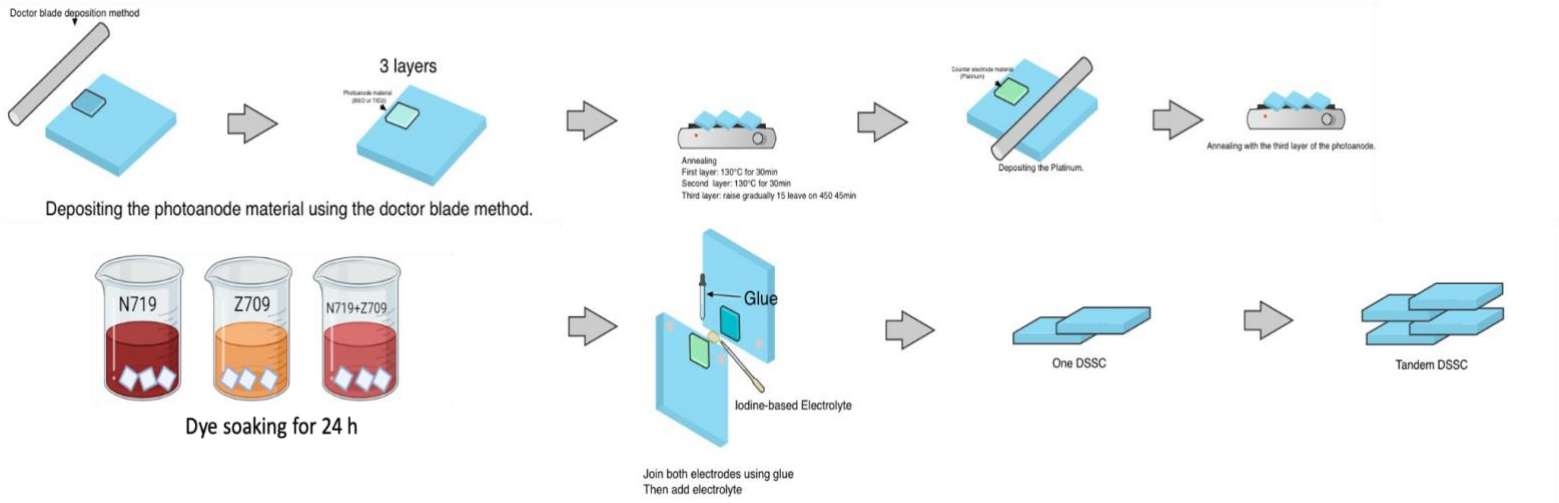
Firstly, the photoanode was prepared by depositing the three layers of $BaSnO_3$ paste on the FTO glass using a doctor blade method one by one layer sequent after drying every layer was annealed at 120°C for 10 min on a hot plate. Then, after the third layer of the paste gradually increase the temperature to 450°C and endures for 35 minutes. Next, the substrates were dipped into di-tetrabutylammoniumcis-bis(isothiocyanato)bis(2,2′-bipyridyl-4,4′-dicarboxylato) ruthenium (II)), or known as N719 ruthenium complex dye and, soaking for 24 hours which makes it the first sample. The second sample was dipped into a cobalt complex dye called Z709 dye. Then, the third sample was both dyes together to see if cosensitization would work between the N719 dye and the Z709 dye. Then, the counter electrode, or the cathode, was prepared by depositing platinum over FTO glass using a doctor blade method and then annealed at 120°C for 10 minutes for the first two layers and then for the third layer annealed at 450°C for 35 minutes, which then made the counter electrode ready. Then the two electrodes are sandwiched together using clips. To make the cell conductive, an electrolyte, iodine/triiodide (I^-/I_3^-), was added dropwise between the two electrodes, and the DSSC was ready to be tested.

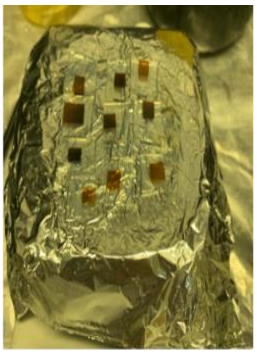
Fabrication of the TIO2-based DSSCs:

The same procedures applied in the BaSnO3-DSSC are applied in this cell, but instead of using BaSnO3 in the photoanode, a regular TiO2 paste was deposited.

Fabricating Tandem DSSC:

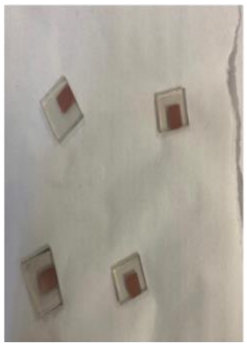
When both the BaSnO3 and TiO2 cells were fabricated and tested, they were joined together by glue. When joined together with glue they are ready to be tested as a tandem solar cell.





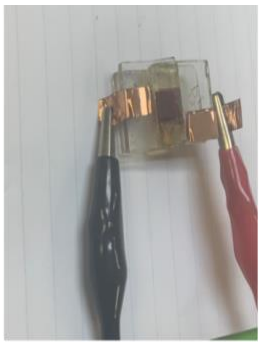
Solar cells on the hotplate

TiO2 cells after dye soaking



BSO based cells after dye soaking

Single DSSCs



Tandem DSSC ready for testing

SECTION 3: RESULTS AND DISCUSSION

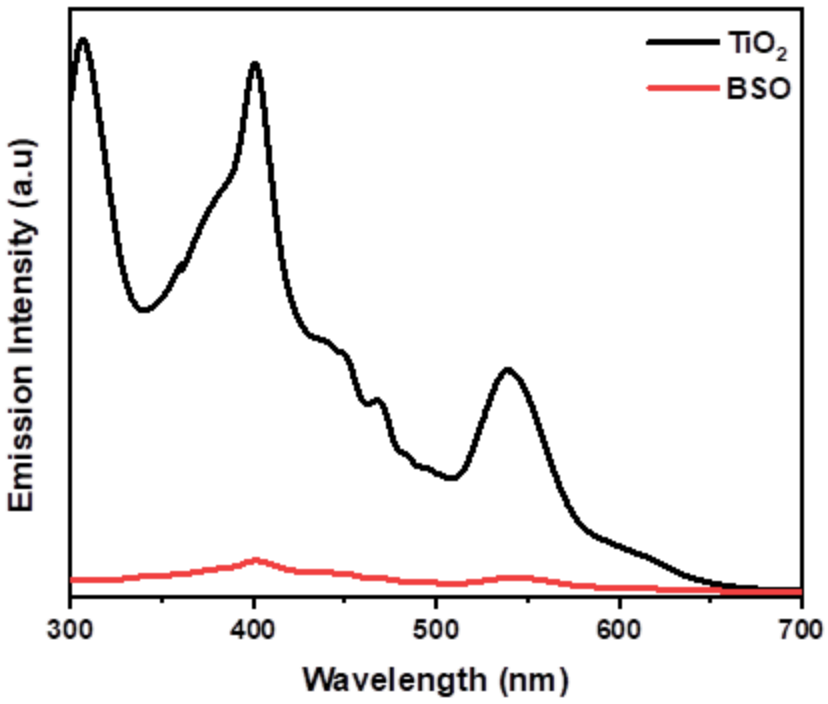


Figure 4. Photoluminescence emission spectra of TiO2 and BSO

This graph shows the photoluminescence (PL) spectra of photo anode TiO2 and BSO with N719 dye. The PL emission peaks centered at approximately 400 and 550 nm can be attributed to the band-to-band emission (electron-hole recombination). There was a decrease in the BSO intensity spectra compared with TiO_2, which can be mainly attributed to the effect of BSO on TiO_2, which decreases the rate of electron-hole recombination which enhances the photovoltaic performance.

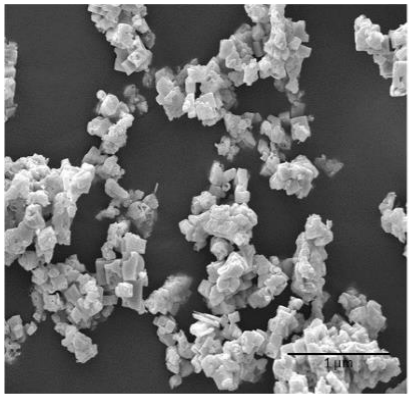


Fig 1: Scanning electron microscope image of BSO

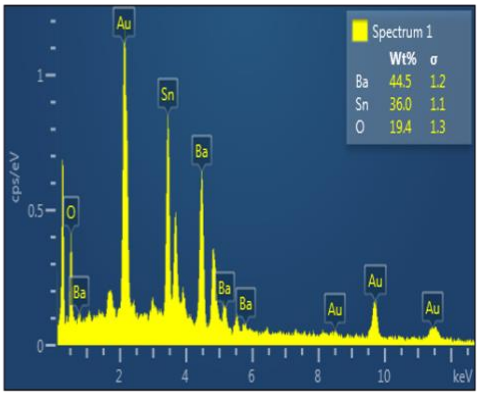


Fig 2: Energy-dipersive X-ray spectroscopy image of BSO

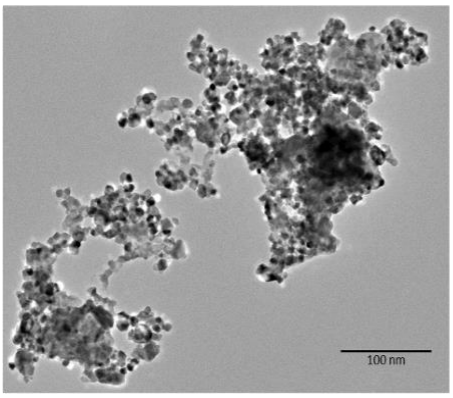


Fig 3: Transmission electron microscope image of BSO

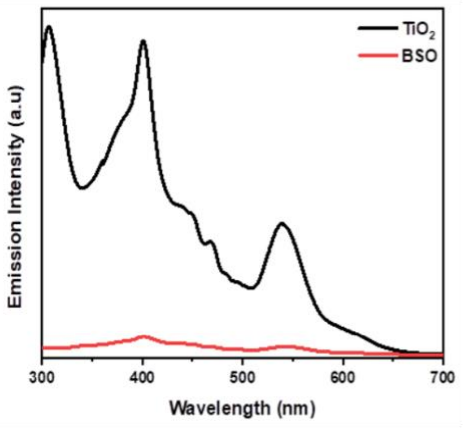


Fig 4: Photoluminescence spectroscopy image of BSO and TiO2

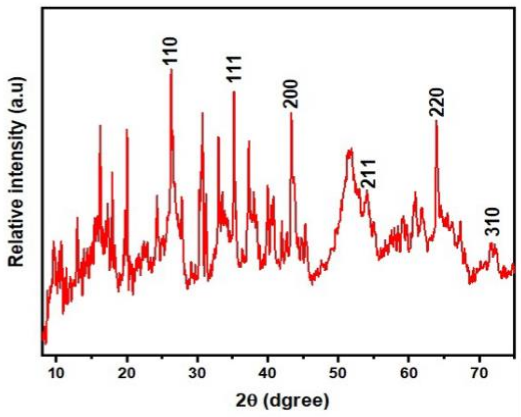


Fig 5: X-Ray diffraction image of BSO

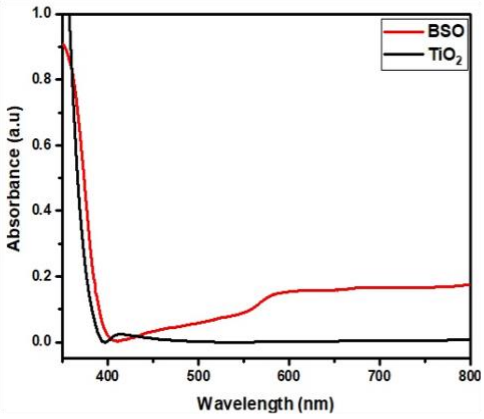


Fig 6: Ultraviolet-visible spectroscopy image of BSO and TiO2

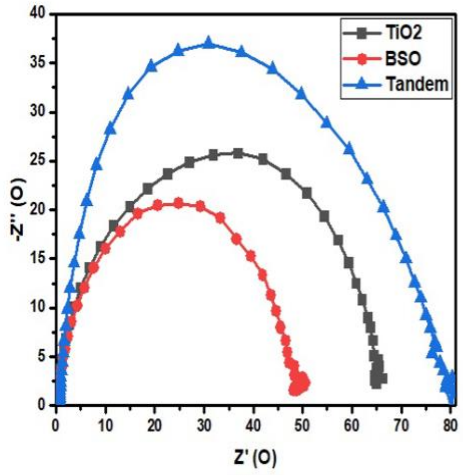


Fig 7: Electrochemical Impedance spectroscopy

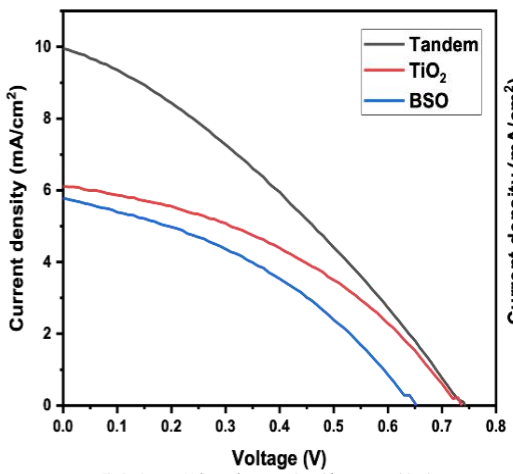


Fig 8: Current-Voltage characterstics without cosensitization

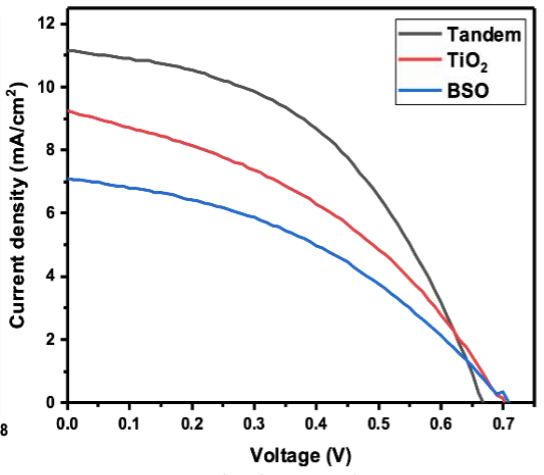


Fig 9: Current-Voltage characterstics with cosensitization

1. Scanning Electron Microscopy (SEM) of Barium Stannate:

The SEM analysis revealed the morphological features of Barium Stannate, showcasing its surface characteristics. The observed microstructure provides insights into the material's potential for enhanced electron transport in solar cell applications.

2. Energy Dispersive X-ray Spectroscopy (EDS) of Barium Stannate:

The EDS image offered elemental composition information, confirming the purity and composition of Barium Stannate. The precise elemental distribution is crucial for understanding the material's electronic properties and its suitability for tandem dye-sensitized solar cells (DSSCs).

3. Transmission Electron Microscopy (TEM) of Barium Stannate:

TEM analysis allowed for a detailed examination of the internal structure of Barium Stannate. The nanoscale insights gained from this imaging technique contribute to the understanding of the material's structural integrity and its impact on charge transport within the solar cell.

4. X-ray Diffraction (XRD) Image of Barium Stannate:

The XRD analysis provided crystallographic information, revealing the phase composition and crystallinity of Barium Stannate. This information is crucial for assessing the material's suitability as a photoactive layer in tandem DSSCs.

5. Ultraviolet-Visible (UV-Vis) Spectroscopy of Barium Stannate and Titanium Dioxide:

The UV-Vis spectroscopy images of both Barium Stannate and Titanium Dioxide showcased their absorption spectra. The synergistic absorption properties of these materials suggest their potential as complementary components in tandem DSSCs, optimizing light harvesting across a broader spectral range.

6. Electrochemical Impedance Spectroscopy (EIS) of Barium Stannate and Titanium Dioxide Solar Cells, and Tandem Solar Cells:

EIS provided insights into the electrochemical behavior of Barium Stannate and Titanium Dioxide solar cells, as well as the tandem solar cell configuration. The impedance data aids in understanding charge transport and recombination processes, guiding further optimization strategies for enhanced device performance.

7. Current-Voltage Characteristics Without Cosensitization:

The current-voltage characteristics revealed the individual performance of Barium Stannate and Titanium Dioxide solar cells, as well as the tandem solar cell, without cosensitization. Understanding the intrinsic behavior of each component is crucial for assessing their compatibility in tandem configurations.

8. Current-Voltage Characteristics With Cosensitization:

The current-voltage characteristics with cosensitization demonstrated the impact of co-sensitization on the overall device performance. This collaborative approach aims to improve light absorption and charge transfer efficiency in tandem DSSCs, potentially enhancing their power conversion efficiency.

9. I-V curves:

Column1	Tandem	TiO_2	BSO
0	9.955	6.114	5.78
0.01	9.913	6.093	5.745
0.02	9.858	6.093	5.71
0.03	9.809	6.072	5.682
0.04	9.767	6.016	5.633
0.05	9.676	5.995	5.605
0.06	9.634	5.995	5.556
0.07	9.551	5.967	5.515
0.08	9.509	5.919	5.494
0.09	9.418	5.891	5.459
0.1	9.356	5.863	5.389
0.11	9.265	5.842	5.361
0.12	9.174	5.8	5.319
0.13	9.105	5.8	5.305
0.14	9.021	5.737	5.236
0.15	8.944	5.709	5.215
0.16	8.833	5.681	5.159
0.17	8.728	5.647	5.124
0.18	8.644	5.626	5.054
0.19	8.526	5.577	5.013
0.2	8.435	5.556	4.978
0.21	8.324	5.5	4.936
0.22	8.226	5.451	4.887
0.23	8.101	5.396	4.789
0.24	8.003	5.354	4.748
0.25	7.885	5.333	4.692
0.26	7.766	5.284	4.65

0.27	7.654	5.214	4.566
0.28	7.508	5.193	4.504
0.29	7.397	5.124	4.441
0.3	7.271	5.082	4.364
0.31	7.146	4.991	4.28
0.32	7.013	4.943	4.232
0.33	6.895	4.894	4.162
0.34	6.769	4.817	4.057
0.35	6.609	4.747	3.988
0.36	6.497	4.678	3.89
0.37	6.372	4.629	3.834
0.38	6.197	4.531	3.709
0.39	6.065	4.475	3.625
0.4	5.953	4.392	3.534
0.41	5.786	4.294	3.437
0.42	5.619	4.224	3.339
0.43	5.479	4.134	3.242
0.44	5.34	4.05	3.151
0.45	5.187	3.966	3.012
0.46	5.047	3.876	2.921
0.47	4.866	3.806	2.788
0.48	4.74	3.716	2.656
0.49	4.566	3.583	2.531
0.5	4.406	3.499	2.384
0.51	4.252	3.416	2.266
0.52	4.099	3.297	2.147
0.53	3.932	3.179	2.008
0.54	3.771	3.074	1.847
0.55	3.611	2.942	1.687
0.56	3.444	2.83	1.547
0.57	3.255	2.698	1.373
0.58	3.088	2.586	1.206
0.5899	2.921	2.433	1.052
0.6	2.726	2.286	0.857
0.61	2.544	2.168	0.683
0.62	2.363	2.007	0.481
0.63	2.168	1.833	0.285
0.64	1.98	1.68	0.285
0.65	1.812	1.533	0.069
0.66	1.589	1.338	-0.307
0.67	1.408	1.15	-0.572

0.68	1.206	0.969	-0.795
0.69	0.976	0.78	-1.032
0.7	0.767	0.606	-1.297
0.7099	0.564	0.397	-1.534
0.72	0.348	0.195	-1.792
0.73	0.167	0.216	-2.043
0.74	0.09	-0.168	-2.315
0.75	-0.293	-0.426	-2.58
0.7599	-0.509	-0.656	-2.845
0.77	-0.767	-0.872	-3.117
0.78	-1.011	-1.095	-3.41
0.79	-1.241	-1.311	-3.689
0.8	-1.485	-1.527	-3.995
0.8099	-1.715	-1.785	-4.253
0.82	-1.945	-2.015	-4.56
0.83	-2.189	-2.231	-4.846
0.84	-2.406	-2.489	-5.181
0.8499	-2.684	-2.719	-5.494

Table1: I-V curve of cells without cosensitization

Cell ID	Tandem
Operator	AD
Comment	
Intensity (W/cm^2)	0.1
Cell Area (cm^2)	0.25
Test System	OAI IV Tester
Test Date	1/26/2023 3:54:48 PM
Test Type	Light
Efficiency (%)	14.028
Voc (V)	0.668

Isc (A)	NaN
Jsc (mA/cm^2)	NaN
Fill Factor (%)	NaN
Vmp (V)	0.43
Imp (A)	0.008155
Jmp (mA/cm^2)	32.62
Pmax (W)	0.003507
R series (Ohm*cm^2)	5.169809
R shunt (Ohm*cm^2)	NaN

Data

V Dark (V)	I Dark (A)	V Light (V)	I Light (A)	V Low Light (V)	I Low Light (A)	Power (W)
		0.85	-0.012695			-0.01079
		0.84	-0.011615			-0.009756
		0.83	-0.010681			-0.008865
		0.82	-0.00983			-0.00806
		0.81	-0.009			-0.00729
		0.8	-0.008206			-0.006564
		0.79	-0.007467			-0.005898
		0.78	-0.006721			-0.005242

0.77	-0.006031	-0.004643
0.7599	-0.005347	-0.004064
0.7499	-0.004678	-0.003508
0.74	-0.004023	-0.002977
0.73	-0.003409	-0.002489
0.72	-0.002796	-0.002013
0.71	-0.002217	-0.001574
0.7	-0.001646	-0.001152
0.69	-0.001095	-0.000755
0.68	-0.000551	-0.000375
0.67	-0.000077	-0.000052
0.66	0.000299	0.000198
0.65	0.00092	0.000598
0.64	0.001401	0.000897

	0.63	0.001875	0.001181
	0.62	0.002328	0.001443
	0.61	0.002753	0.001679
	0.6	0.003165	0.001899
	0.59	0.003555	0.002097
	0.58	0.003945	0.002288
	0.57	0.004294	0.002447
	0.56	0.004663	0.002611
	0.55	0.005026	0.002764
	0.54	0.005333	0.002879
	0.53	0.005667	0.003004
	0.52	0.005939	0.003088
	0.51	0.006239	0.003182
	0.5	0.006532	0.003266
	0.49	0.006804	0.003334
	0.48	0.007048	0.003383
	0.47	0.007271	0.003417
	0.46	0.007536	0.003466
	0.45	0.007759	0.003491

0.44	0.007947	0.003496
0.43	0.008163	0.00351
0.42	0.008344	0.003504
0.41	0.008505	0.003487
0.4	0.008672	0.003468
0.39	0.008825	0.003442
0.38	0.008993	0.003417
0.37	0.009097	0.003366
0.36	0.00923	0.003323
0.3499	0.009355	0.003274
0.3399	0.009453	0.003213
0.33	0.009592	0.003165
0.32	0.009669	0.003094
0.31	0.009753	0.003023
0.3	0.009857	0.002957
0.29	0.009927	0.002878
0.28	0.009983	0.002795
0.27	0.010052	0.002714
0.26	0.010157	0.002641

	0.25	0.010185	0.002546
	0.24	0.010254	0.002461
	0.23	0.010331	0.002376
	0.22	0.010436	0.002296
	0.21	0.010478	0.0022
	0.2	0.010533	0.002107
	0.19	0.010575	0.002009
	0.18	0.010631	0.001913
	0.17	0.010673	0.001814
	0.16	0.010708	0.001713
	0.15	0.010756	0.001613
	0.14	0.01077	0.001507
	0.13	0.010826	0.001407
	0.12	0.010833	0.0013
	0.11	0.010854	0.001194
	0.1	0.010896	0.001089
	0.09	0.010924	0.000983
	0.08	0.010959	0.000876
	0.07	0.010979	0.000768

0.06	0.011014	0.000661
0.05	0.011014	0.000551
0.04	0.011056	0.000442
0.03	0.01107	0.000332
0.02	0.011105	0.000222
0.01	0.011133	0.000111
0	0.011154	0

Table2: I-V curve of Tandem solar cell with cosensitization

In summary, the comprehensive analysis of Barium Stannate and Titanium Dioxide, both individually and in tandem configurations, provides valuable insights into the fabrication of highly efficient and cost-effective tandem DSSCs for building-integrated photovoltaics. The combination of advanced characterization techniques and performance assessments lays the groundwork for further advancements in the field of solar energy harvesting.

Measures	**TiO_2-DSSC**	**BSO-DSSC**	**Tandem DSSC**
PCE (%)	9.9	8	14
Voc (V)	0.69	0.7	0.66
FF (%)	38	40	47

Table3: summary of result of this research results,

SECTION 4: INTERPRETATION & CONCLUSIONS

The hypothesis was proved that the fabrication of a Tandem dye-sensitized solar cell and using N719 and Z709 as the dye materials exceeded more than double the typical efficiency for a single-junction dye-sensitized solar cell Moreover, this ideal structure of tandem dye-sensitized solar cell has shown a potential to be used in commercial applications due to its high performance, ease of fabrication, and environmental friendliness.

Future work

Short-term plan:

Synthesizing a novel electrolyte material, since the leakage and freezing of the electrolyte results in stability issues in the solar cell over the time. This makes looking for a substitute to the iodine-based electrolyte critical.

Long-term plan:

A tandem solar cell that is cost-effective and highly efficient would make a great candidate to build a hybrid device of a solar cell and supercapacitor which would be great for building integrated photovoltaics.

SECTION 5: REFERENCES

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This study focuses on developing a straightforward method for fabricating BSO as the electrode in DSSC, demonstrating significantly enhanced efficiency under AM1.0 illumination. A distinctive tandem DSSC was constructed to attain heightened efficiency, and an explanation for the observed improvement behavior needs to be provided. The crystallinity of BSO must be considered during thermal treatment to enhance its crystalline structure for improved efficiency. Further testing of the tandem DSSC under practical conditions, including temperature and humidity variations to address sealing concerns, as well as assessing its stability during long-term operation, is essential.