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Fabrication of Solar Cell using Synthesized Dye-Sensitized and Perovskite Photoactive Layers

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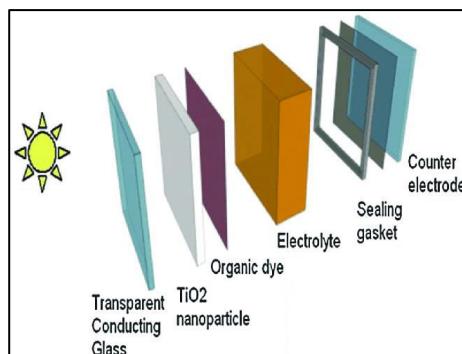
ABSTRACT: This study focuses on the fabrication of high-efficiency solar cells using synthesized dye-sensitized and perovskite photoactive layers. Dye-sensitized solar cells (DSSCs) are known for their cost-effectiveness and ease of fabrication, while perovskite materials offer superior light absorption and charge transport properties. By using these materials, this study aims to enhance the overall photovoltaic performance of the solar cells. The synthesized materials were used in fabrication of solar cells and the fabricated solar cells were tested, showing significant improvements in efficiency compared to conventional DSSCs.

KEYWORDS: Solar, dye, perovskite, material, fabrication.

I. INTRODUCTION

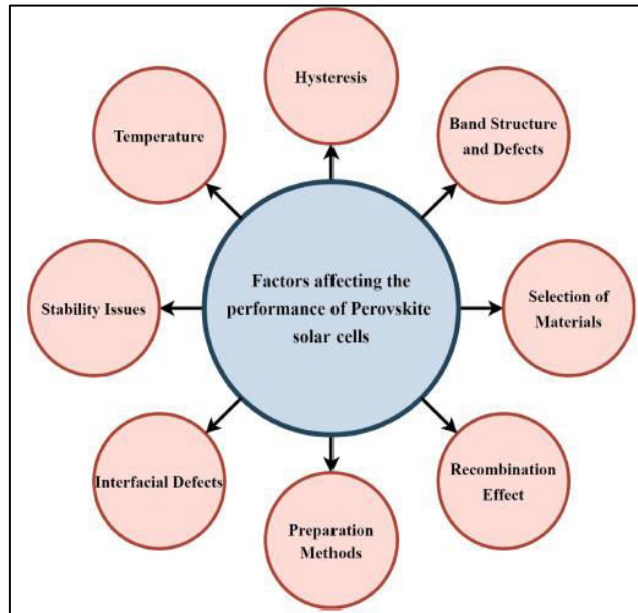
DSSC (a solar device) has attracted significant interest in improving its efficiency through various interventions. When exposed to light, the device functions as a reliable and self-sustaining mechanism for converting solar energy into electricity. Certain unfavorable reactions that lead to reductions in cell efficiency also occur. An essential determinant is the substantial surface area and thickness of the semiconductor film, which enhances the amount of dye that can be loaded, thereby increasing the optical density and facilitating efficient light absorption. Nuclear fission, which is projected to be the most viable alternative, poses significant environmental concerns and challenges related to waste management. Therefore, it is advisable to choose the another option, which may be DSSCs. DSSCs have been created as a cost-effective alternative, but, their effectiveness in practical applications remains inadequate. Therefore, it is necessary to do extensive research on all potential facets of DSSCs. However, it is necessary to adopt a comprehensive approach that considers all these factors together. A typical DSSC consists of four main components shown in the figure:

Fig 1: Components of DSSC



For commercial use, a DSSC (dye-sensitized solar cell) must be able to last for more than 25 years when used in building-integrated modules. This is to prevent any disruptions to the building functioning caused by the need for repairs or replacements. Nevertheless, DSSCs are currently bulky because of their layered glass construction. However, they have to make a trade-off with a lower lifespan.

Fig 2: Factors Affecting Efficiency of Solar Cells



The stability and longevity of a DSSC are likely to be influenced by the encapsulation and sealing. In addition to the use of costly glass substrates for modules and panels, a major challenge is the production of glass that is uniformly flat at the scale of $10\ \mu\text{m}$ over surfaces bigger than $30 \times 30\ \text{cm}^2$, while also considering the impact of humidity. Another obstacle is the selection of metal interconnects in the cells that exhibit varying degrees of corrosion to the electrolyte.

The DSSC consists of a collection of functional electrodes that are saturated with a sensitizer or dye. These electrodes are then sealed to the counter electrode. Furthermore, various techniques can be used for increasing efficiency of DSSCs.

1. The regeneration process should be significantly faster than the process of dye oxidation, which is known as recombination and takes between 0.1 to $30\ \mu\text{s}$. The highest dye absorption occurs at the working electrode (WE) when the porosity of the TiO_2 nanoparticles is increased.
2. The entrapment of nanoporous TiO_2 nanoparticles is done by an electrolyte solution. Therefore, it is necessary to sensitize the working electrode uniformly with a sensitizer.
3. By advocating for the utilization of diverse materials such as nanotubes, carbon nanowires, and graphene in the production of electrodes, employing alternative electrolytes, efficiency of these cells can be significantly enhanced.
4. Phosphorescent or luminous chromophores can be inserted into the DSSC by applying them. Plasmonic phenomena can also be utilized for this purpose.

Perovskite materials and technology have made progress in manufacturing and are being researched for commercializing perovskite solar cell systems. The large-scale manufacture of PSCs is currently not possible due to multiple issues. The challenges encountered by perovskite solar cells and modules include the need for cost-effective and scalable fabrication methods to produce high-quality perovskite layers, the selection and application of charge extraction layers, the development of low-cost processes for creating bottom and top electrodes. To construct small- and large-area PSC devices, it is imperative to resolve these concerns. Moreover, the successful commercialization of perovskite solar cells relies on other crucial variables, including longevity, stability, the harmful effects of lead, environmental pollution, and cost-effectiveness. Perovskite compounds exhibit exceptional tolerance to crystalline defects due to their ionic interaction. In addition, these materials have low breakdown temperatures, which results in lower thermal stability compared to Si. The perovskite thin film is composed of several crystals and can exhibit variations in the orientation of its unit cells. Even a slight modification in the process of creating and combining substances can result in a significant transformation in the structure and appearance, which can have a profound effect on how well the device functions.

II. EXPERIMENTAL PROCEDURE

A variety of dye/perovskite sensitizer complex systems were analyzed for their potential use in DSSCs and PSSCs. The study used following photosensitizers:

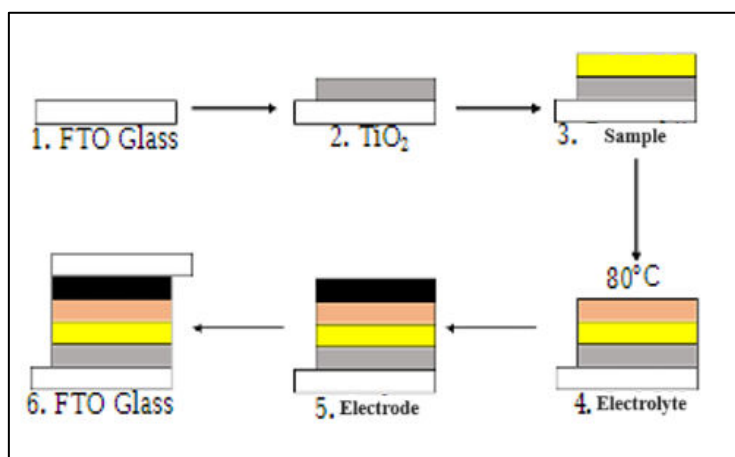
Natural plant dyes: Phyllanthus urinaria (Quercetin 7-Methyl Ether), Berberis asiatica (Berberine) and Cassia bakeriana (Epicatechin).

Perovskite-based sensitizers: Propylammonium tri-lead iodide ($\text{CH}_3\text{CH}_2\text{CH}_2\text{NH}_3\text{PbI}_3$), Butyl ammonium tri-lead iodide ($\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{NH}_3\text{PbI}_3$) and $\text{CH}_3\text{CH}_2\text{NH}_3\text{SnCl}_3$ dye.

The fabrication of solar cell with synthesized dye and perovskite material involved the following steps:

Fabrication: The Scotch tape was affixed to the four corners of the conducting side of the FTO glass. The TiO_2 paste was spread evenly and levelled using a razor blade on the same surface of the FTO glass. Following the flattening procedure, the FTO glass was subjected to annealing on a heated plate at a temperature of around 450°C for a duration of 30 minutes. After a duration of 30 minutes, the FTO glass was allowed to cool in the ambient atmosphere before being immersed in the sample solution (sensitizers) for a period of one day. Regarding the counter electrode, graphite was applied to the conducting surface of another FTO glass. The TiO_2 /dye electrode was extracted from the dye solution and subsequently cleansed with ethanol to eliminate any debris. A few drops of the electrolyte solution were applied onto the TiO_2 /dye layer. The electrode and counter electrode were secured together using binder clips, with their surfaces facing each other.

Fig 3: Fabrication of Solar Cell



Efficiency Measurement: The performance of solar cells was evaluated using both perovskite materials and natural plant-based dyes. The performance metrics measured included open-circuit voltage (V_{oc}), short-circuit current (I_{sc}), fill factor, and solar cell efficiency.

Table 1: Observation Table

Dyes	V_{oc}	I_{sc}	Solar Irradiance	Fill Factor	Efficiency (%)
Perovskite Material					
$\text{CH}_3\text{CH}_2\text{NH}_3\text{SnCl}_3$	0.41	58.11	512	0.84	3.90
$\text{CH}_3\text{CH}_2\text{CH}_2\text{NH}_3\text{PbI}_3$	0.39	56.51	512	0.85	3.65
$\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{NH}_3\text{PbI}_3$	0.34	51.88	512	0.87	2.99
Plant-based Dye					

Phyllanthus urinaria	0.42	59.42	512	0.83	4.04
Berberis asiatica	0.45	61.54	512	0.81	4.38
Cassia bakeriana	0.38	56.89	512	0.85	3.58

Three perovskite materials were evaluated in which $\text{CH}_3\text{CH}_2\text{NH}_3\text{SnCl}_3$ emerged as the most efficient among the perovskite sensitizers, achieving a solar cell efficiency of 3.90%. This material recorded an Voc of 0.41 V, Isc of 58.11 mA, and a fill factor of 0.84. These results indicate a strong performance, with the material showing good potential for light absorption and energy conversion. $\text{CH}_3\text{CH}_2\text{CH}_2\text{NH}_3\text{PbI}_3$ demonstrated slightly lower efficiency at 3.65%, with a Voc of 0.39 V and an Isc of 56.51 mA. The fill factor for this material was slightly higher at 0.85, suggesting that while its voltage and current outputs were lower than $\text{CH}_3\text{CH}_2\text{NH}_3\text{SnCl}_3$, its overall energy conversion efficiency remained competitive. $\text{CH}_3\text{CH}_2\text{CH}_2\text{NH}_3\text{PbI}_3$ showed the lowest efficiency among the perovskite materials, with an efficiency of 2.99%. It had the lowest Voc at 0.34 V and an Isc of 51.88 mA, but the highest fill factor at 0.87. Despite the higher fill factor, the lower voltage and current outputs limited its overall performance.

The study also investigated the performance of natural plant-based dyes, which showed promising results. Berberis asiatica was the most efficient sensitizer overall, achieving a solar cell efficiency of 4.38%. It recorded the highest Voc of 0.45 V and the highest Isc of 61.54 mA among all tested dyes. Despite having a slightly lower fill factor of 0.81 compared to the perovskite materials, its high voltage and current outputs significantly contributed to its superior efficiency. Phyllanthus urinaria also demonstrated strong performance, with an efficiency of 4.04%. This dye had a Voc of 0.42 V and an Isc of 59.42 mA, along with a fill factor of 0.83. These results indicate that Phyllanthus urinaria is a highly effective natural dye for use in DSSCs. Cassia bakeriana showed a lower efficiency compared to the other plant-based dyes, with an efficiency of 3.58%. It recorded a Voc of 0.38 V and an Isc of 56.89 mA, with a fill factor of 0.85. Although it was less efficient than Berberis asiatica and Phyllanthus urinaria, it still performed competitively with the perovskite sensitizers.

III. CONCLUSION

The study's findings highlight the potential of natural plant-based dyes as efficient sensitizers for dye-sensitized solar cells. Both Berberis asiatica and Phyllanthus urinaria outperformed the tested perovskite materials in terms of overall efficiency, suggesting that natural dyes could be viable and environmentally friendly alternatives in DSSC technology. The higher efficiencies observed in plant-based dyes underscore the importance of further research into optimizing natural dye extraction and processing methods to enhance their performance. Additionally, these results open up new possibilities for the development of sustainable and cost-effective solar energy solutions using natural resources.

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