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I-V characterization of Dye Synthesised Solar Cells based on Composites of Azo dyes and Nitrogen doped TiO_2 Nanoparticles

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ABSTRACT

Dye-Sensitized Solar Cells (DSSCs) have become a potential technology for converting sunlight into electricity because of their significant visible light absorption, high molar extinction coefficients, high efficiency, abundance, stability and nontoxic nature[1][9]. Azo dyes in particular have demonstrated tremendous potential as DSSC Sensitizers[11][12]. TiO_2 is frequently used as the photoanode in DSSCs, where it absorbs light and produces electrons. The surface area, particle size, and crystal structure of TiO_2 are factors which determine its performance in a DSSC[14]. It has been found that TiO_2 with an Anatase Crystal Structure, a large surface area, and small particle size performs better in DSSC[16][17].

DSSCs were prepared with composites of 4 Azo dyes(Methylene Blue, Methyl Orange, Eriochrome Black T and Alizarin Red), pure TiO_2 and n-doped TiO_2. The performance of each DSSC was evaluated through I-V characteristics. It was discovered that the N-doped TiO_2 based DSSC with Methylene blue azo dye gave promising results in terms of fill factor and efficiency.

Keywords : Dye Sensitised Solar Cell (DSSC), Azo Dye, TiO_2 Nano-particles, N-doped TiO_2, I-V Characteristics of DSSC, Doctor Blade

I. INTRODUCTION

The Dye-Sensitized Solar Cell (DSSC) is a third-generation solar cell that is being researched as a strong alternative to Silicon-based Solar Cells[13]. However, to accelerate the industrialization of DSSCs, improvements in efficiency are necessary[2][10]. In the construction of the DSSC, two Indium Tin Oxide (ITO) glass plates are used. One ITO glass plate is coated with a monolayer of Titanium Dioxide (TiO2) and dye molecules, serving as the anode. It absorbs light and initiates the electron excitation process[4][6]. The other ITO glass plate functions as the counter electrode, coated with a layer of carbon made from carbon soot[7][15]. The carbon counter electrode facilitates the redox process in the electrolyte, completing the electrical circuit. An electrolyte solution containing a redox mediator, specifically I-

/I3-, is introduced between the two ITO glass plates [3][5]. This solution acts as a bridge, connecting the anode and the counter electrode, facilitating the transfer of electrons and maintaining charge balance. The redox mediator plays a crucial role in ensuring the proper flow of electrical current and completing the electrochemical reactions within the DSSC.

In our previous study [8], we extensively investigated the absorption spectra of composites made using four different Azo dyes, namely Methylene Blue, Methyl Orange, Eriochrome Black T, and Alizarin Red, pure TiO_2 and also Nitrogen doping on TiO2 nanoparticles. It was found that Nitrogen doping led to a reduction in the band gap of pure TiO_2 nanoparticles. Among the dyes tested, the combination of Nitrogen-doped TiO_2 nanoparticles with Methylene Blue exhibited the most favourable results in terms of optical absorption characteristics[18].

In this research paper, we have investigated the current-voltage (I-V) characteristics of Dye-Sensitized Solar Cells (DSSCs) with a focus on the Anode and Cathode preparation techniques. The anode is prepared using composites of pure and Nitrogen-doped TiO_2 through the doctor blading technique. The cathode is prepared using a candle soot-based carbon material. Our objective is to gain insights into the electrical performance of these DSSCs and evaluate the effectiveness of the pure and Nitrogen-doped TiO2 composites in combination with different Azo dyes. Here, using two different types of TiO_2 nano powders pure and N-doped TiO_2 we constructed eight DSSCs with various Azo Dyes—Methylene Blue, Methyl Orange, Eriochrome Black T, and Alizarin Red and carried out the characterization.

II. EXPERIMENTAL DETAILS

2.1 Materials

The following list of resources was utilised to prepare the DSSC.

- TiO_2 Nano powder, Pure and N-doped TiO_2 prepared using Sol-Gel method
- Plates made of Indium Tin Oxide (ITO) which have dimensions of 25mm by 25mm and thickness of 0.7mm and the resistance less than 10 ohms
- Azo dyes—Methylene Blue, Methyl Orange, Eriochrome Black T, and Alizarin Red
- (I^-/I_3^-) electrolyte solution
- Acetic acid solution with pH =3
- Carbon (Soot)

2.2 Photo anode preparation

a. ITO plates Cleaning

For the best results it was ensured that ITO plates are cleaned properly by dipping them in Ethanol solution for 1 hour and then ultrasonicated for 30 minutes. 8 samples of DSSC were prepared. I-V characteristics of each sample were obtained using a simple testing method.(Figure 5A)

b. Azo Dye Preparation

Azo Dyes—Methylene Blue, Methyl Orange, Eriochrome Black T, and Alizarin Red were mixed with distilled water having pH in the neutral region. All the dye samples were prepared at 1000 ppm.

c. Preparation of Anode paste for anode coating on ITO plates

A thick paste was produced by mixing the acetic acid solution with TiO_2 particles. This paste was coated on an ITO plate using the Doctor Blading method. All of the various coated ITO plates were immersed in an Azo dye solution for 24 hours after being allowed to dry for an hour in order to achieve the best possible dye molecule absorption[19][20]. The ITO plates were keptin a Muffle furnace for annealing at 450 degrees celsius for 2 hours. Samples were also prepared using composites of N-doped TiO_2 and various Azo dyes.

d. Counter Electrode Preparation

The soot layer on the ITO plates was prepared using a candle flame deposition method. After igniting the candle and establishing a steady flame, the ITO plates were positioned at an optimal distance above the flame. By adjusting the distance and exposing the plates for a specific duration, the carbonaceous material in the candle combusted generating soot particles that deposited onto the plates. This process was repeated multiple times to achieve a uniform and well-defined soot layer. The resulting soot-coated ITO plates provide a reliable substrate for further investigations in the field of dye-sensitive solar cells[21][22].

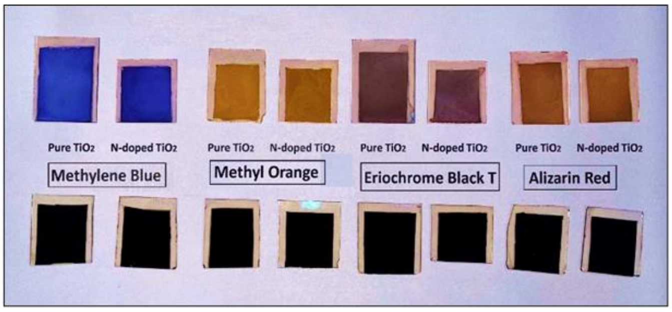

Figure1: Comparative Imaging of ITO Plates with TiO_2 Nano powder and Diverse Dyes and Carbon Soot

2.3 DSSC fabrication

- ITO plates were first cleaned using Ethanol solution and ultrasonic bath, to remove any contaminants.
- Anode was formed by putting a layer of Titanium Dioxide (TiO_2) nanoparticles onto an ITO plate.
- Dye sensitization- The TiO_2 coated substrate was immersed into the dye solution containing the chosen dye, allowing sufficient time for the dye molecules to get absorbed onto the TiO_2 surface. This process was conducted under dark conditions to avoid dye degradation by light.
- Cathode layer- Another ITO plate was used to make the counter electrode, and the conducting side was prepared by repeatedly passing it through a candle flame to coat it in soot.

Electrolyte preparation-Electrolyte solution waspreparedconsisting of iodide/triiodide ($I^-/I3^-$) The electrolyte acts as a medium for charge transport and regeneration of the dye.

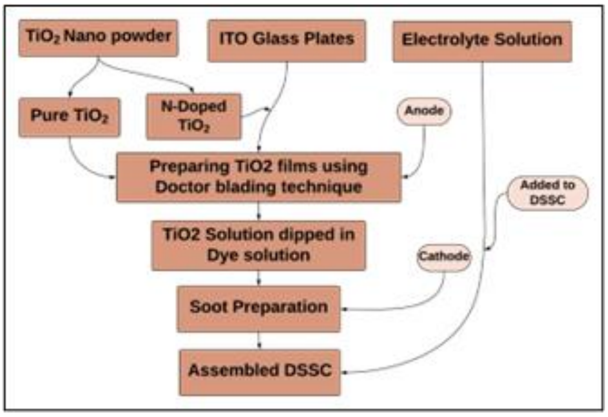

Figure 2 : Dye-Sensitized Solar Cell assembly flowchart

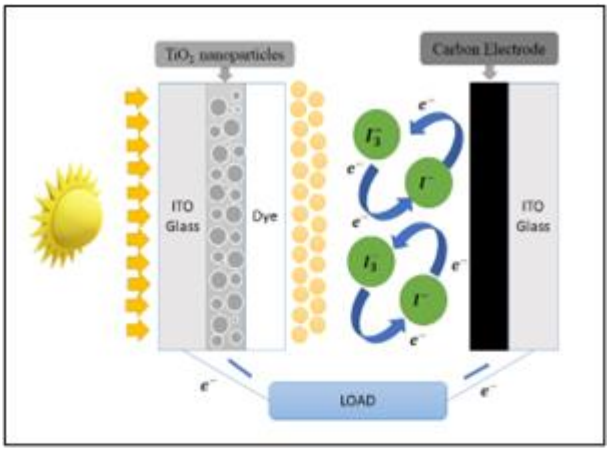

Figure3: Schematic representation of working principle of DSSC

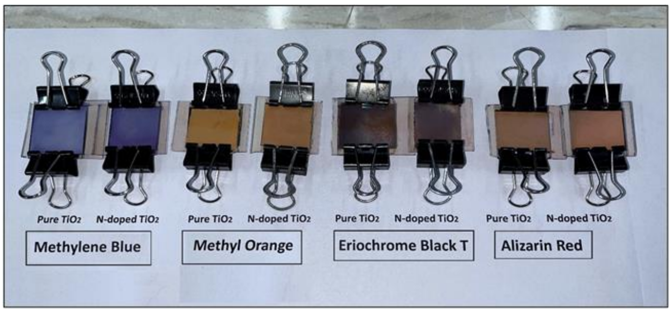

Figure 4 : DSSC devices of Pure and N-Doped TiO_2 with all four Dyes (Methylene Blue, Methyl Orange, Eriochrome Black T and Alizarin Red)

2.4 The Characterization Method of the DSSC:

We have designed a special testing circuit to evaluate the functionality of our Dye-Sensitized Solar Cell (DSSC). With the help of this circuit, we can quickly assess the DSSC's electrical characteristics. A variable resistor, DSSC, ammeter, voltmeter, and wires constitute the testing circuit. The DSSC's current is measured by an ammeter. On the other hand, the voltmeter measures the voltage across the DSSC. We plotted the current-voltage (I-V) characteristics of DSSCs by meticulously adjusting the input voltage and measuring the associated current and voltage. The circuit layout is shown in Figure 5A, and the experimental setup for the DSSC is shown in Figure 5B[23].

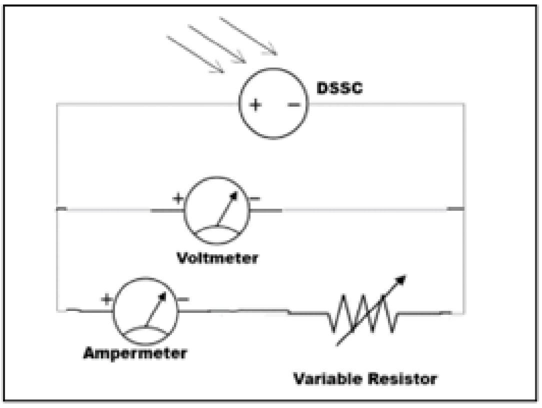

Figure 5A: Circuit schematic for measuring the current-voltage characteristics of the (DSSC) Solar Cell

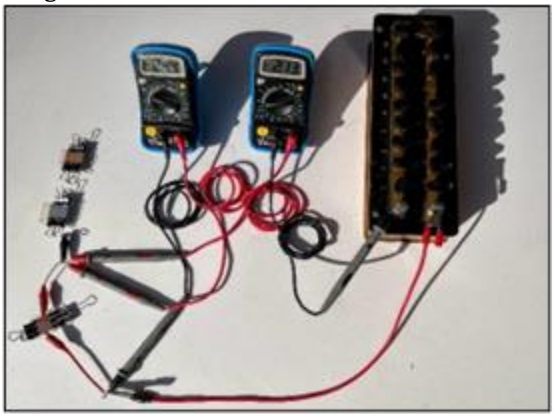

Figure 5B : Experimental Setup for DSSC Performance Evaluation

III. RESULTS AND DISCUSSION

3.1 I-V Characteristics

I-V characterization is crucial for comprehending the functionality and effectiveness of Dye-Sensitized Solar Cells (DSSCs). It involves the measurement of important parameters such as short-circuit current (Isc), fill factor (FF), and open-circuit voltage (Voc) using the Current-Voltage (I-V) technique. Isc represents the maximum current generated by the DSSC in the absence of external load, while FF indicates the quality of the current-voltage curve and the efficiency of power conversion. Voc is the voltage across the DSSC in an open-circuit condition. These measurements provide valuable insights into the performance and behaviour of DSSCs, allowing for optimization and further development of these solar cells.

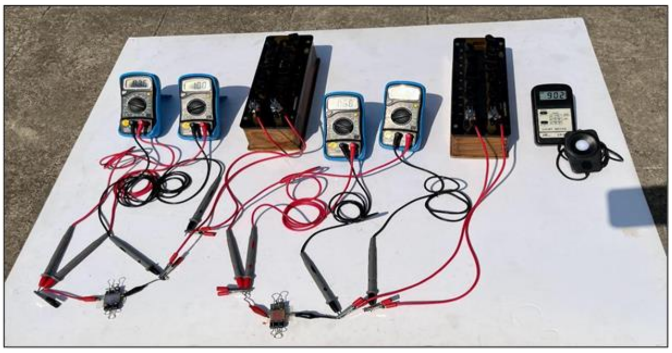

Figure 6: Side-by-Side Testing of Two DSSCs in Equal Sunlight Illumination
(Measuring sunlight intensity with a lux meter)

Table 1: Comparison of I-V Characteristics for DSSCs Prepared with 4 Different Azo Dyes with Pure/N-Doped TiO_2

Dyes		Short Circuit Current I_{sc} (mA)	Open Circuit voltage (v)	Fill Factor %	Efficiency η %
Methylene Blue	N-Doped TiO_2	0.5824	0.6368	54.81	2.85
	Pure TiO_2	0.4930	0.6357	50.07	2.20
Methyl Orange	N-Doped TiO_2	0.5091	0.5414	48.67	1.88
	Pure TiO_2	0.4592	0.5407	45.10	1.57
Eriochrome Black T	N-Doped TiO_2	0.4961	0.5366	35.04	1.31
	Pure TiO_2	0.4504	0.5032	22.66	0.72
Alizarin Red	N-Doped TiO_2	0.4652	0.5162	24.01	0.80
	Pure TiO_2	0.4194	0.5050	21.18	0.62

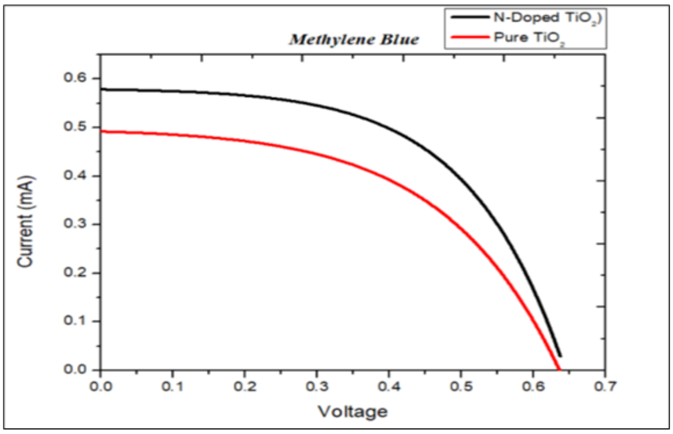

Figure 7: Comparative I-V Characteristics of DSSCs with Methylene Blue Dye: Pure vs. N-Doped TiO_2

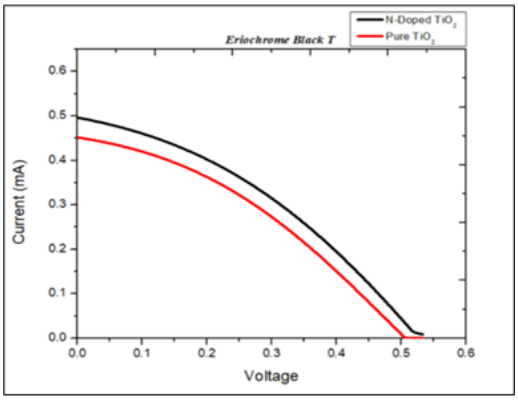

Figure 8: Comparative I-V Characteristics of DSSCs with Eriochrome Black T Dye: Pure vs. N-Doped TiO_2

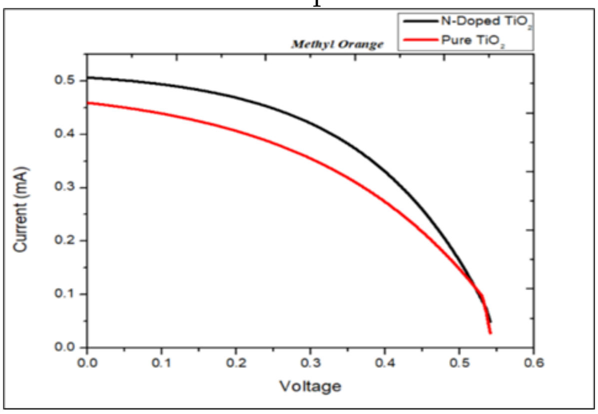

Figure 8: Comparative I-V Characteristics of DSSCs with Methyl Orange Pure vs. N-Doped TiO_2

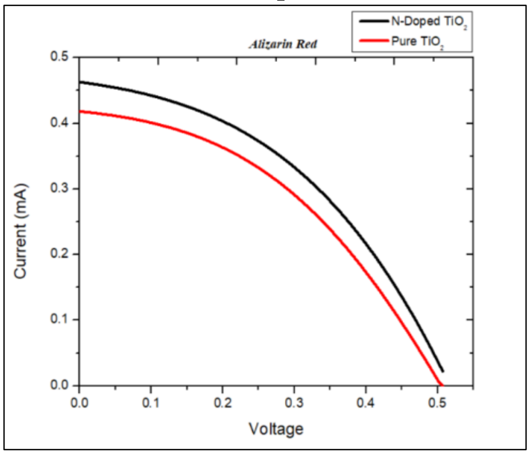

Figure 9: Comparative I-V Characteristics of DSSCs with Alizarin Red Dye: Pure vs. N-Doped TiO_2

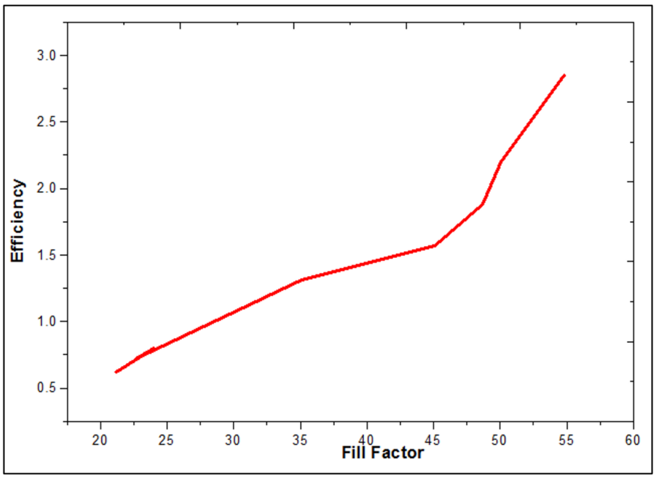

Figure 10: Graph of Efficiency versus Fill Factor

IV. CONCLUSION

The I-V characteristics of Dye-Sensitized Solar Cells (DSSCs) were analyzed for four different dyes, namely Methylene Blue, Methyl Orange, Eriochrome Black T and Alizarin Red. These DSSCs were prepared using both pure TiO_2 and N-doped TiO_2 as the photoanode material. Among the tested configurations, the best results were obtained for the DSSC prepared with N-doped TiO_2 with Methylene Blue dye. The I-V characteristics of this particular combination exhibited superior performance in terms of key parameters such as short-circuit current (Isc), open-circuit voltage (Voc), and fill factor (FF). The enhanced efficiency observed in the N-doped TiO_2 DSSC with Methylene Blue dye suggests the synergistic effect of nitrogen doping and the specific dye-sensitizer in enhancing the charge transport and light absorption properties of the solar cell.

This finding highlights the potential of utilizing N-doped TiO_2 and Methylene Blue dye as a promising combination for improving the performance of DSSCs.

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