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Constructing a Dye sensitized solar cell for renewable energy production

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Abstract

The increasing global need for renewable and environmentally friendly energy sources has directed attention toward alternative photovoltaic technologies. Among these technologies, Dye-Sensitized Solar Cells (DSSCs) have emerged as a promising low-cost and eco-friendly solution compared to traditional silicon-based solar cells. In this project, a DSSC was constructed using fluorescein sodium dye as the sensitizer. The photovoltaic properties of the dye-Sensitized solar cell with fluorescein sodium were investigated. The solar cell gives a short circuit current of 0.723 mA, an open circuit voltage of 0.59 V. and the cell efficiency =0.57% by illuminating the cell with a lamp whose power density equals 100 mW/cm^2.

Key Words:
Dye sensitized solar cell, Fluorescein dye, Photovoltaic Cell

1. **Introduction**:

There is a continuous growth in the world's energy needs (Mehmood et al, 2014). The world heavily relies on hydroelectric and thermal electric energy sources, most of which are non-renewable. (Cari et al,2020) However, these non-renewable resources are rapidly depleting each year due to the increasing demand for energy.(Francis et al, 2012; Consiglio et al, 2023) The utilization of renewable energy sources, such as solar power, can play a significant role in addressing potential shortages in energy supply.(Gong et al, 2012; Zulkifili et al, 2013). As a form of renewable energy, solar energy offers a practical and sustainable solution to help mitigate the risk of energy insufficiency (See et al, 2020; Wei et al, 2010). Dye-sensitized solar cells (DSSCs) have emerged as a promising alternative to conventional solar cells, thanks to their low manufacturing costs and Moderate efficiency. In these cells, the conversion of visible light into electrical energy is achieved through the sensitization of a wide band gap material. Therefore, dye molecules are essential, serving as the key component responsible for absorbing the incoming light. (Maged et al, 2018; Shalini et al, 2016)

Fluorescein dye is used in dye-sensitized solar cells (DSSCs) for its distinctive properties, it effectively absorbs light in the visible spectrum, enhancing the conversion of solar energy into electricity. Also, it remains stable over time, ensuring consistent performance without degradation. Moreover, it interacts well with materials like titanium dioxide (TiO_2), improving conversion efficiency. Also, it's structure can be adjusted to enhance optical properties based on environmental conditions. Thus, Fluorescein plays a crucial role as a sensitizer in dye-sensitized solar cells due to its strong absorption in the 470–500 nm range and its ability to emit in the green region (510–550 nm). When fluorescein absorbs light, it excites electrons to a higher energy state. These excited electrons can then be transferred to the conduction band of a semiconductor material, such as titanium dioxide, generating an electric current. The efficiency of this process depends on minimizing the energy lost to radiative recombination. (O'Regan et al, 1991) Fluorescein’s strong light-harvesting ability and its effective electron excitation make it a valuable component in enhancing the performance of DSSCs and improving solar energy conversion efficiency. (AL Hussainey, et al, 2018)

In this work, we fabricated a dye sensitized solar cell with Fluorescein Sodium Salt dye using simple techniques. Then, we carried out electrical measurements for this solar cell and calculated its efficiency under light illumination.

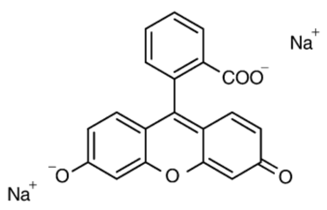

Figure 1: Structure of fluorescein sodium salt.

2. The Theoretical Framework:

2.1 Transparent Conductive Substrate:

Dye-Sensitized Solar Cells (DSSCs) are typically assembled using two sheets of transparent conductive materials. These serve as substrates for the deposition of the semiconductor and the catalyst, while also functioning as current collectors. (Lupan et al, 2010)

To ensure maximum sunlight reaches the active layer of the cell, the substrates must possess high optical transparency—typically greater than 80%. Additionally, they should exhibit excellent electrical conductivity to facilitate efficient charge transport and minimize energy losses. Together, these two key properties—high transparency and good electrical conductivity—play a vital role in determining the overall efficiency of DSSCs. FTO (fluorine-doped tin oxide, SnO_2:F) and ITO (indium tin oxide, In_2O_3:Sn) are widely used as conductive substrates. They consist of soda-lime glass coated with a conductive layer of either fluorine-doped tin oxide or indium tin oxide. (Mehmood et al, 2014, p. 2; Andualem et al, 2018). ITO films have a transmittance greater than 80% and a sheet resistance of 18 Ω/cm^2, while FTO films exhibit a transmittance of around 75% in the visible region and a sheet resistance of 8.5 Ω/cm^2 . (Andualem et al, 2018; Francis et al, 2021)

2.2 Mesoporous Semiconductor:

Acting as a conductive medium, the semiconductor provides ample surface area for dye adsorption, captures electrons released by the excited dye, and channels them toward the external circuit to produce an electric current (Hoffmann et al, 1995).The electron transport rate, which is strongly influenced by factors such as crystallinity, morphology, and the surface area of semiconductors, plays a critical role in determining the efficiency of Dye-Sensitized Solar Cells (DSSCs). Metal oxides, such as titanium oxide (TiO_2), are commonly used in this context. (Lupan et al, 2010, 70) Titanium dioxide (TiO_2) films are applied to the surfaces of substrates like metal foils, flexible polymer films, and conductive glass. The deposition of semiconductors is performed using different techniques, with subsequent thermal treatments at varying temperatures to ensure the semiconductor materials adhere properly to the substrate (Abdel-Latif et al, 2015)

2.3 Dye:

Function of the Dye (Photosensitizer):

The dye absorbs light energy and uses that energy to transfer electrons to the conduction band (CB) of the semiconductor. This is a key step in converting light energy into electrical energy.

An efficient photosensitizer in a solar cell needs to absorb visible light, adhere to the semiconductor surface, have strong light absorption properties, stay stable after oxidation, and have the right energy levels to facilitate electron transfer between the dye, semiconductor, and electrolyte (Mehmood et al, 2014; Giribabu et al, 2013).

2.4 Electrolyte:

The electrolyte's primary function is to regenerate the dye after it has injected electrons into the conduction band of the semiconductor. In dye-sensitized solar cells (DSSCs), the electrolyte layer facilitates charge transfer, directing positive charges toward the counter electrode. The long-term performance of DSSCs is significantly influenced by the electrolyte's properties. (Ito et al, 2005) An ideal electrolyte solvent should have low vapor pressure, very low viscosity, high dielectric constant, and a high boiling point. From an industrial standpoint, additional factors such as ease of processing, chemical stability, and environmental sustainability are also important. At present, the most effective redox mediator used in DSSCs is a liquid electrolyte containing the iodide/triiodide redox couple. This electrolyte consists of iodine, iodides, and often other additives. Ionic liquids present a promising alternative due to their high thermal and chemical stability, non-volatility, and excellent ionic conductivity. Discovering an optimal redox couple remains a key challenge for future research in DSSCs (Adedokun et al, 2016)

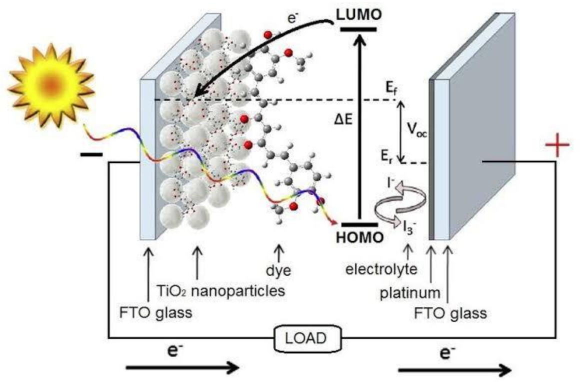

Figure 2: Schematic diagram of the DSSC.(Abdul Alim et al.2022)

The Current-Voltage (I-V) curve of a solar cell illustrates its electrical characteristics. On the plot, the y-axis represents current, and the x-axis represents voltage. Key points on the I-V curve include:

Short-Circuit Current (Isc): The current when the terminals are shorted, and voltage is zero.

Open-Circuit Voltage (Voc): The voltage when the terminals are open, and current is zero.

Maximum Power Point (Pmax): The point where current multiplied by voltage is maximized, representing the cell's highest efficiency.

The solar cell efficiency (η) is the ratio of the maximum power point (Pmax) to the input light irradiance (E) under standard test conditions and A_c is the cell's surface area in cm². It is calculated as:

$$\eta = \frac{Pm}{E \times Ac}$$

FF is the fill factor calculated from the following equation:

$$FF = \frac{Vmax \times Jmax}{Voc \times Jsc}$$

(Hagfeldt et al, 2000; Mat Isa et al, 2015)

3.Methods of Research and the tools used

0.5 g of TiO_2 powder was transferred into a beaker then 1ml of distilled water, 1 drop of Triton X 100 and 1.5 ml of acetic acid were added dropwise subsequently into the beaker. The above mixture was Stirred overnight until the paste is formed (Hagfeldt et al, 2000). The TiO_2 colloid was dropped on the FTO glass plate using a doctor blade technique. The TiO_2 porous film was sintered by firing the conducting glass sheet at 450°C in air for 30 min. After cooling to 80°C, the TiO_2 film was immersed in concentrated dye for 24 h to absorb the dye adequately, then the dye sensitized TiO_2 film was washed with anhydrous ethanol and dried in moisture-free air. Sputtered Pt over FTO was the counter electrode. The two electrodes were clipped together. A DSSC was assembled by filling an electrolyte solution (0.6M tetra propylammonium iodide, 0.1M iodine, 0.1M lithium iodide, 0.5M 4-tertbutylpyridine (TBP) in acetonitrile) between the dye sensitized TiO_2 electrode and a platinized conducting glass electrode. (Hafez et al, 2011)

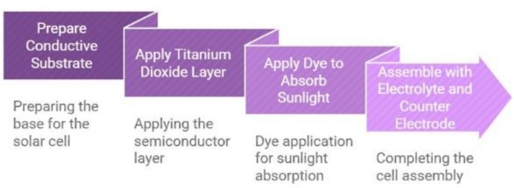

Figure 3: Dye-Sensitized Cell Construction

The photoluminescence (PL) emission measurement of the fluorescein dye was obtained using a PerkinElmer LS55 Luminescence Spectrometer (USA) and the absorption spectrum was recorded using JASCO V-530 spectrometer (Japan).

To measure the I-V curve, vary the load resistance and record the current, then calculate the voltage using Ohm's law. Solar power meter was used to measure the solar radiation intensity in $mWcm^{-2}$.

I_{sc} is short circuit current generated under illumination, and V_{oc} is the open circuit voltage.

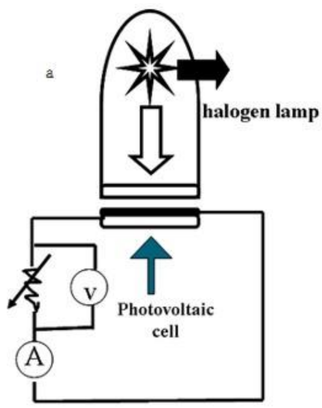

Figure 4: The solar cell in the electric circuit

4. Results of Research

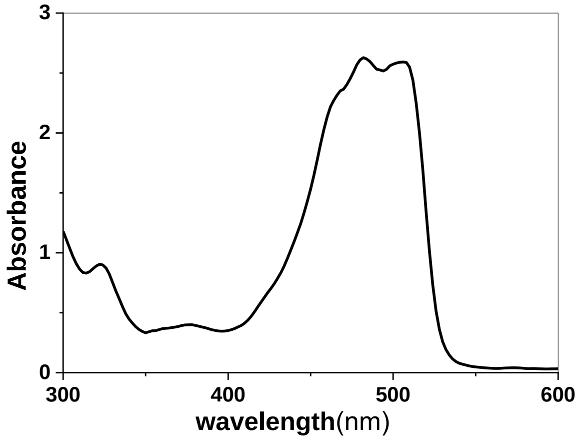

Figure 5: Absorption spectrum for fluorescein in ethanol.

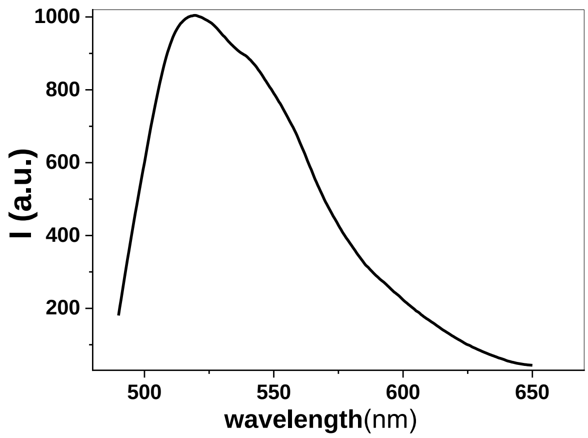

Figure 6: Emission spectrum for fluorescein in ethanol.

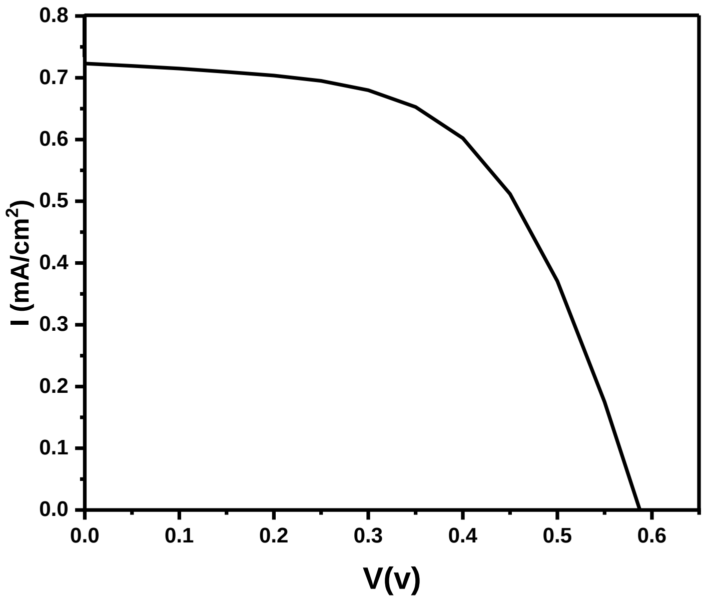

Figure 7: I–V curves for DSSC

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Table 1: The solar cell parameters obtained from the I–V curve for DSSC fabricated by fluorescein dye

I_{sc}	V_{oc}	I_{max}	V_{max}	FF	η%
0.723	0.59	0.602	0.4	0.555	0.57%

5. Interpretation of Results

Before conducting the absorption spectrum measurement, a baseline was established using ethanol, which has minimal absorption. The sample was placed in a cuvette and inserted into the spectrophotometer, which scanned from 200 to 750 nm in 2 nm steps. The absorption spectrum of fluorescein dissolved in ethanol, shown in Figure 1, Fluorescein strongly absorbs light in the blue-green region of the visible spectrum, displaying two notable peaks around 484 nm and 506 nm. The absorption process involves the transition of electrons from the ground singlet state (S_0) to the first excited singlet state (S_1). This efficient light absorption makes fluorescein highly suitable for applications that rely on capturing visible light, particularly in photonic and photovoltaic systems. Upon excitation, (AL Hussainey, et al, 2018) fluorescein emits fluorescence with a peak around 520 nm, falling into the green region of the visible spectrum. This emission results from the relaxation of the molecule from the S_1 state to the ground state S_0. A typical Stokes shift of ~36 nm is observed. (Alwan et al, 2015) The electronic transitions in fluorescein are primarily of the π-π^* type, which are characteristic of aromatic molecules with conjugated double bonds. These transitions occur between the ground singlet state (S_0) and the first excited singlet state (S_1), maintaining singlet multiplicity—meaning there is no change in the electron spin. This spin-allowed transition enables high fluorescence efficiency. The transition from the excited state (S_1) back to the ground state (S_0) results in the emission of visible light, which is a key feature in fluorescein's strong photoluminescent behavior which confirms fluorescein's suitability for applications requiring visible light conversion and demonstrates its strong photoluminescent efficiency. (Kristoffersen et al, 2018)

The photocurrent–voltage properties of the DSSC was measured and shown in Fig.7. The I-V curve obtained from the experiment demonstrates the solar cell's performance under the given experimental conditions. It was characterized by a short circuit current (Isc) of 0.723 mA and an open-circuit voltage (Voc) of 0.59 V which suggests that the cell generates a reasonable voltage, reflecting its ability to interact with light effectively. The fill factor (FF) of 0.555 shows a good level of energy conversion efficiency. However, the calculated efficiency of 0.57% indicates a moderate current output under illumination. Thus, the experiment shows promising results, and with further research and optimization, improvements in efficiency are expected. (Hagfeldt et al, 2000)

6. Conclusion

Fluorescein Sodium Salt dye sensitized solar cell based on nanostructure TiO_2 was synthesized. we estimated the solar cell parameters V_{oc} (open circuit voltage) = 0.59 volts, I_{sc} (short-circuit current) =0.723 mA, and the cell efficiency = 0.57% by illuminating the cell with a lamp whose power density equals 100 mW/cm^2.

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