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IMPLEMENTATION OF A DYE SENSITIZED SOLAR CELL

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Abstract
This study used spinach extract, ipomoea leaf extract and their mixed extracts as the natural dyes for a dye-sensitized solar cell (DSSC). Spinach and ipomoea leaves were first placed separately in ethanol and the chlorophyll of these two kinds of plants was extracted to serve as the natural dyes for using in DSSCs. In addition, the self-developed nanofluid synthesis system prepared a TiO2 nanofluid with an average particle size of 50 nm. Electrophoresis deposition was performed to let the TiO2 deposit nanoparticles on the indium tin oxide (ITO) conductive glass, forming a TiO2 thin film with the thickness of 11.61_m. This TiO2 thin film underwent sintering at 450 ◦C to enhance the compactness of thin film. Finally, the sintered TiO2 thin film was immersed in the natural dye solutions extracted from spinach and ipomoea leaves, completing the production of the anode of DSSC. This study then further inspected the fill factor, photoelectric conversion efficiency and incident photon current efficiency of the encapsulated DSSC. According to the experimental results of current–voltage curve, the photoelectric conversion efficiency of the DSSCs prepared by natural dyes from ipomoea leaf extract is 0.318% under extraction temperature of 50 ◦C and pH value of extraction fluid at 1.0. This paper also investigated the influence of the temperature in the extraction process of this kind of natural dye and the influence of pH value of the dye solution on the UV–VIS patterns absorption spectra of the prepared natural dye solutions, and the influence of these two factors on the photoelectric conversion efficiency of DSSC.

Keywords: ***Solar Cell, DSSC, Henna Leaves, Spectrophotometer Analysis, FTO Glass, Natural Dyes.***

Introduction
The demand for renewable energy is rising, with solar cells representing a viable solution to reduce reliance on fossil fuels and address environmental concerns. Dye-sensitized solar cells (DSSCs) present an alternative to conventional silicon-based photovoltaic cells due to their lower production costs, adaptability to various applications, and potential to use environmentally friendly materials. The innovation of DSSCs, pioneered by Michael Grätzel and Brian O'Regan in 1991, enables electricity generation by mimicking photosynthesis, utilizing natural dyes to convert sunlight into electric energy .

Problem Statement
DSSCs face challenges in achieving high energy conversion efficiency, particularly due to the organic dyes and liquid electrolytes that may degrade over time. This research addresses these issues by using henna (Lawsonia inermis) as a natural dye sensitizer, aiming to develop a cost-effective, renewable power source.

Objectives
The primary aim of this study is to create a DSSC using henna as a sensitizer, providing an alternative to silicon-based cells. The objectives include improving cost-efficiency, assessing the viability of henna in DSSCs, and identifying performance factors in comparison with other natural dyes.

Literature Review

Historical Context of DSSCs

The origins of DSSCs link back to the 19th century with foundational studies in photochemistry. In the 1990s, Grätzel's introduction of nanocrystalline TiO_2 marked a significant advancement, achieving up to 7% efficiency, with subsequent improvements reaching over 10% efficiency due to better dye materials

Types and Function of Solar Cells

Solar cells are categorized across generations. Traditional crystalline silicon solar cells, still dominant due to their high efficiency, fall under first-generation cells, while DSSCs represent third-generation technology. DSSCs operate by separating light absorption from charge transportation, utilizing components such as FTO glass, TiO_2, and natural dyes for low-cost and flexible energy solutions.

DSSC Components and Functionality

Key components include:

- **Fluorine-Doped Tin Oxide (FTO) Glass**: Used for its high conductivity and stability.
- **Titanium Dioxide (TiO_2)**: Acts as a scaffold for dye attachment, critical for electron transfer upon sunlight exposure.
- **Dye Sensitizer**: Henna was chosen for its accessibility and ability to absorb visible light, though limitations exist in conversion efficiency compared to synthetic dyes.

Methodology

DSSC fabrication involves several essential aspects and can be separated into three Categories: substrate surface texturing, transparent conductive oxide layer deposition and cell assembly. This section describes the detailed research procedures and methodology on how the DSSC sample is fabricated with textured substrates.

Materials used include:

Titanium Dioxide (TiO_2) Ti-nanoide T37/sp from solaronix, Conductive (fluorine doped tin dioxide coated) transparent glass from solaronix, stirring rod (1 piece included), Pencil for sizing, Petri dishes (15 pieces included), Plastic spoon (1 piece included), Transparent tape (1 roll included), Alligator clips, Iodine electrolyte solution , 99% ethanol, Distilled water, Filter paper, Aluminum foil, Henna leave, Furnace, Microscopic slide glass, Mesh (mesh count of 120), Digital weighing Balance, Sealant (Amosil – 4R) double sided, Glass cutter , Propanol, PVA (polyvinyl alcohol), Ti CL_4 (Titanium tetra-chloride), Steering machine/hot plate, Electronic Dryer, Metal pot, Meter rule, Hand glove , Cover slides 100st/pc(22 x 32mm), Glass cover slip, Plain Metal sheet, Platinum, Pt-catalyst T/SP from solaronix, Multimeter and various laboratory equipment such as spectrophotometers for dye verification.

Experimental Procedure

Dye Extraction from Henna Leaves

Henna leaves (Lawsonia inermis) were used to extract natural dye. 20 grams of henna leaves were measured and combined with a 40 ml solvent mixture, consisting of 20 ml ethanol (99% absolute) and 20 ml distilled water. The blend was left in a covered flask for 24 hours, wrapped in aluminum foil to block sunlight and preserve dye potency.

Dye Verification on TiO_2

To verify dye adhesion to titanium dioxide (TiO_2), a cover slip (cheaper than FTO glass) was coated with TiO_2 using the screen-printing method. The dye's staining ability was confirmed by analyzing the dyed slip with an ultraviolet spectrophotometer.

Screen Printing Method

Screen printing was chosen to evenly apply TiO_2 on the cover slip. A mesoporous mesh facilitated liquid passage, optimizing sunlight absorption. The mesoporous design enables greater surface area exposure to light, enhancing solar cell efficiency.

Drying and Sintering

TiO_2 was adhered to the cover slip through drying, done by heating in a furnace at 120°C for 30 minutes. For stronger adhesion, the coated slip was sintered at 300°C for 30 minutes. Sintering for FTO glass would require 400°C for 40 minutes. The sintered slip was allowed to cool to prevent delamination of the TiO_2 layer.

Impregnation

For dye-sensitized solar cells (DSSCs), the TiO_2-coated slip was soaked in the henna dye solution for 24 hours, rinsed with propane, and verified for its staining capability on TiO_2.

Electrode Preparation

The FTO glass electrode was cut to 1.5 cm by 2.5 cm. Its conductive side was checked for continuity, then cleaned with 99% ethanol and dried. The conductive area was masked with polyvinyl alcohol (PVA) to isolate the negative terminal.

Masking

PVA was applied to mask unwanted regions on the FTO substrate, creating a dedicated negative terminal.

Chemical Bath Deposition of Dense TiO_2

Dense TiO_2 was created by mixing distilled water and titanium tetrachloride. The FTO glass, masked with tape to cover the uncoated side, was submerged in the solution in a boiling water bath for 30 minutes. This deposition enhances conductivity, reduces risk of short circuits, and prevents electrolyte contact with the FTO glass during assembly.

Screen Printing, Sintering, and Impregnation of FTO Glass Substrate

After screen printing TiO_2 on the FTO glass, it was dried at 120°C for 30 minutes, then sintered at 400°C for 40 minutes. After cooling, it was immersed in the henna dye solution for 24 hours, rinsed, and dried, completing the electrode for the DSSC's negative terminal.

Counter Electrode Preparation

Another FTO glass substrate was cut, its conductive side verified, and cleaned. A platinum catalyst was deposited using screen printing, then dried and sintered following the same process as the electrode. Cooling the glass to below 100°C ensured the platinum layer adhered without peeling.

Sealing of Electrodes

Insulating spacers were placed along the sides of the cell, allowing an electrolyte to flow between electrodes. A sealant (Amosil-4R gum) was applied to bond the electrodes, and the assembly was briefly heated to set the adhesive. The masked PVA area was cleaned, establishing the cell's negative terminal. An iodide electrolyte solution was injected by capillary action, filling the inter-electrode space before sealing the cell.

Electrolyte Filling

Iodine electrolyte solution was carefully introduced to enhance conductivity and facilitate charge flow within the DSS

Results

UV-Vis Spectrophotometer Analysis

The UV-Vis analysis showed an absorption peak for the henna dye around 500 nm, indicating its limited capability to absorb in the desired range for higher efficiency. The absorbance spectrum results revealed moderate effectiveness in light absorption, suitable for preliminary DSSC applications but with potential for improvement

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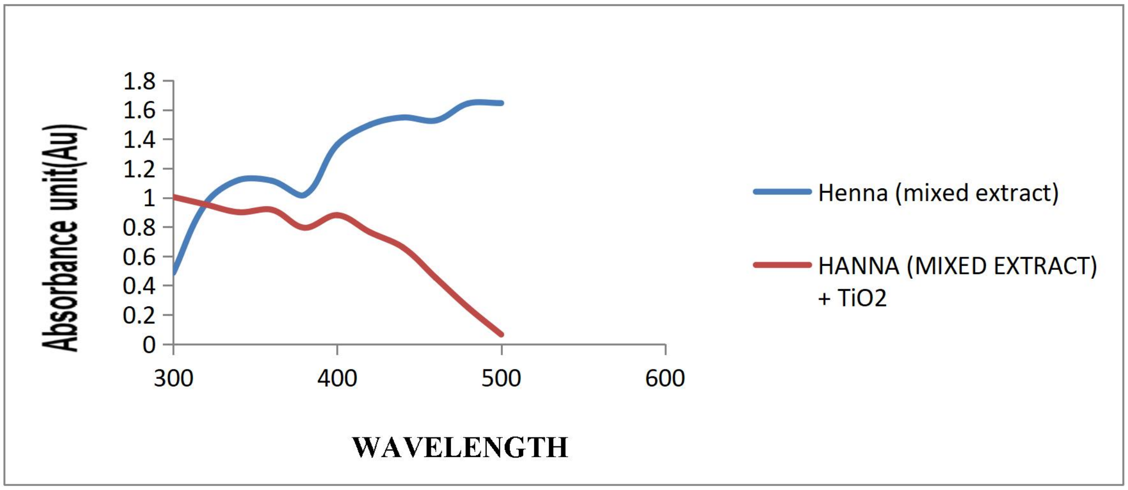

Fig 1.0: Absorbance of dye and absorbance of dye on Ti0$_2$

I-V Characteristics

Using a solar simulator, the I-V curve was generated, revealing a short-circuit current (Jsc) of 3.16 mA/cm² and an open-circuit voltage (Voc) of 0.409 V, yielding an efficiency (η) of approximately 0.075%. This performance reflects the limitations of the natural henna dye, especially when compared to synthetic dyes like ruthenium-based dyes, which can achieve much higher efficiencies.

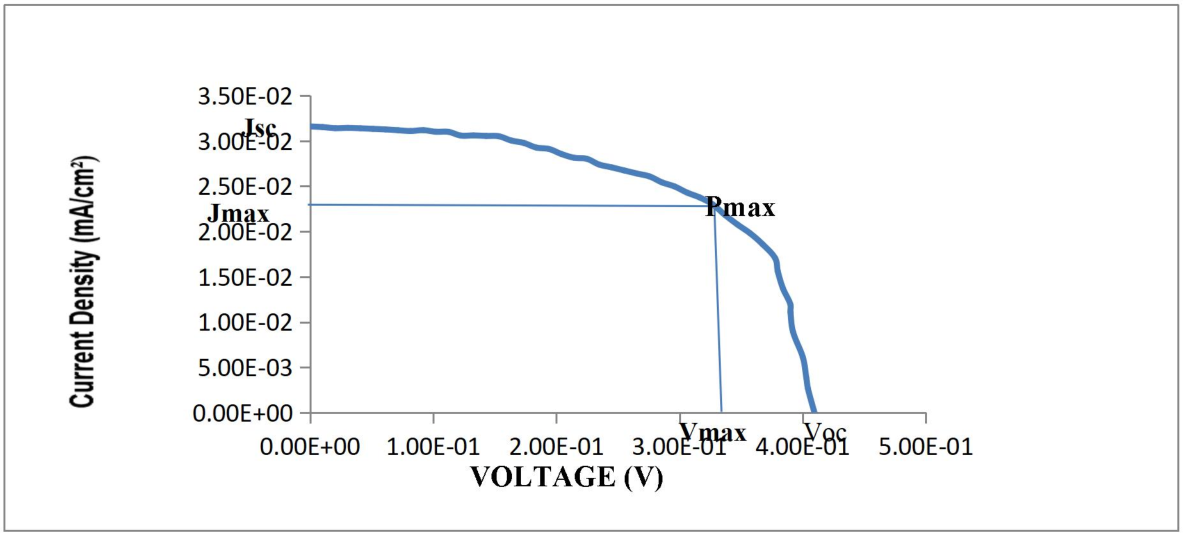

Fig 1.2; I-V characteristics of DSSC using natural dye extracted from Henna leaf

Calculations

The length and breadth of the cell was measured to be 1.3 cm and 0.8 cm respectively. The area of the cell was calculated to be. Area of the cell = 1.3 cm x 0.8 cm = 1.04 cm^2. From the figure 4.3 the value of the short circuit current J_{sc} =3.16X 10-^{2}mA/ cm^2 when the open circuit voltage V_{oc} = 0 and also, the value of the open circuit voltage V_{oc} =0.40955V when the short circuit current density J_{sc} = 0

From IV characterization:

The maximum voltage V_{max} = 0.31641V, I_{max} = 2.30 x 10^{-02}mA/cm^2

$P_{max} = V_{max} \times I_{max}$

P_{max} = 0.00752 W

From the IV characteristic curve P_{max} = 0.00752 W

$V_{oc} \times J_{sc} = 0.40955 \times 3.16 \times 10^{-02} = 0.012942$

$$FF = \frac{\text{Pmax}}{\text{Voc x Isc}} = \frac{0.00752}{0.012942}$$

$FF = 0.581$

$\eta = \frac{\text{Pmax}}{Pin} \times 100$

Now converting P_{in} from W/m^2 to W/cm^2 = 1000/10000 = 0.1W/cm^2

$$\eta = \frac{\text{FF x Voc x Isc}}{\text{Pin}}$$

$$\eta = \frac{0.581 \times 0.012942}{0.1}$$

η = 0.0752

Discussion

Performance and Efficiency of Henna-Based DSSC

The results indicate that henna, as a natural dye, provides a viable, low-cost option for DSSC sensitization, though with a relatively low conversion efficiency. Factors affecting performance include the dye's limited light absorption range and the thickness and particle size of TiO_2 layers used. Studies have shown that other natural dyes, such as anthocyanin, provide better efficiency, suggesting that further optimization is necessary to enhance the henna-based DSSC performance .

Comparative Analysis with Synthetic and Other Natural Dyes

While henna is a cost-effective choice, anthocyanin-based DSSCs have demonstrated superior results with conversion efficiencies up to 0.56%, emphasizing the need for exploring various natural dyes or dye combinations. Additionally, replacing the glass substrate with plastic could improve durability and efficiency.

Conclusion

This study demonstrates that henna-based DSSCs, though less efficient than silicon cells, offer an affordable alternative for renewable energy. The use of natural dyes contributes to sustainable energy research, providing a foundation for further innovation in DSSCs.

Recommendations

To improve DSSC performance, future studies should explore:

- **Darker Dyes**: Utilizing dyes that absorb more light may enhance conversion efficiency.
- **Alternative Substrates**: Plastic substrates could be more cost-effective and efficient compared to glass.
- **Optimized TiO_2 Layers**: Tailoring TiO_2 particle size may yield better electron transport and stability

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