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OPTICAL AND ELECTROCHEMICAL PROPERTIES OF DIFFERENT PHOTOSENSITIZERS IN VARIOUS SOLVENTS USED IN DSSC

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Abstract :Dye-sensitized solar cells (DSSCs) were fabricated using titanium dioxide (TiO_2) nanoparticles and two photosensitizers: lassamine green and phloxin B. Pure anatase phase TiO_2 nanoparticles were synthesized. Lassamine green demonstrated the highest efficiency of 2.23% in dimethyl sulfoxide (DMSO), accompanied by an open-circuit voltage (V_{OC}) of 1907mV, a short-circuit current (i_{SC}) of 1.989mA, and a fill factor (FF) of 0.58. Phloxin B exhibited its peak efficiency of 1.57% in DMSO, with V_{OC} of 1647mV, i_{SC} of 1.812mA, and FF of 0.53.DMSO emerged as the optimal solvent for both sensitizers, as both lassamine green and phloxin B achieved their maximum efficiencies in this solvent, with values of 2.23% and 1.57%, respectively.

I. INTRODUCTION

Solar cells are excellent choices for clean energy sources as they produce electricity without releasing carbon dioxide, a major contributor to global warming [1,2]. O'REGAN and GRATZEL pioneered the Dye-Sensitized Solar Cell (DSSC) technology in 1991 [3]. Dye-Sensitized Solar Cells (DSSCs), or Grätzel cells, are a cutting-edge solar cell technology that harnesses sunlight to generate electricity. These cells employ photoelectric principles to convert solar energy into electrical energy [4-7]. DSSCs typically consist of photoactive semiconductors, such as titanium dioxide, which serve as working electrodes, and counter electrodes. A dye molecule, integrated into the photoanode, plays a crucial role in absorbing sunlight and facilitating efficient electron transfer, thereby enhancing the overall efficiency of the solar cell [8-12].

Three key factors significantly impact the efficiency of a DSSC:i) The dye's light absorption profile [13]; ii) The semiconductor materials employed to capture and transfer electrons from the dye; iii) the dyes or sensitizers implemented.

The dye's ability to absorb light within a specific wavelength range is paramount. For example, curcumin, derived from turmeric, effectively absorbs visible light between 400 and 580 nanometers [14]. The semiconductor material, where the dye is anchored and electrons are collected, plays a vital role. TiO_2 and ZnO are commonly used due to their suitable band gaps and ability to accommodate dye molecules on their porous surfaces [15-24]. DSSCs utilize two primary dye categories: organic and inorganic. Inorganic dyes, such as ruthenium-based complexes, osmium polypyridyl compounds, metal porphyrins, phthalocyanins, and inorganic quantum dots, are widely employed.

The dye's light-absorbing properties are crucial. A dye with higher light absorption in the visible spectrum leads to increased photon absorption, ultimately enhancing the cell's efficiency. In simpler terms, the higher the light absorption efficiency of a dye in the visible spectrum, the greater the number of photons it can capture. DSSCs predominantly utilize two categories of dyes: organic and inorganic. Inorganic dyes commonly comprise metal complexes, such as ruthenium-based compounds, osmium polypyridyl compounds, metal porphyrins, phthalocyanines, and inorganic quantum dots [25].

Typically, DSSCs employ synthetic ruthenium complex dyes like N719, N3, and black dye as sensitizers. TiO_2 photoanodes combined with ruthenium complex dyes have achieved energy efficiencies of 10-11%[26-29]. Sol-gel synthesis is a versatile technique for producing pure TiO_2 nanoparticles. Among photosensitive substances, ruthenium polypyridyl complexes are highly effective inorganic dyes with excellent efficiency [30].

Natural and organic dyes offer a cost-effective and eco-friendly alternative to expensive inorganic dyes. Natural pigments are particularly promising for DSSC sensitization due to their renewable and environmentally friendly nature, ease of production, low cost, purity, and minimal environmental impact[31-34].

To enhance efficiency and pave the way for commercialization, significant research has been dedicated to DSSCs. Literature reviews underscore the potential of natural dyes for various applications. However, despite notable advancements, DSSCs still face challenges in terms of reproducibility, reliability, and the development of novel photosensitizers and other components essential for commercialization. These factors impede their widespread adoption. Nevertheless, the prospect of affordable, high-efficiency DSSCs remains encouraging, necessitating continued research and development to fully unlock their potential in the solar energy market.

II. MATERIALS AND METHODS

Dyes

Two dyes are selected for the research Lassamine Green and Phloxin B. The molecular structure of these dyes are shown in fig. 1.

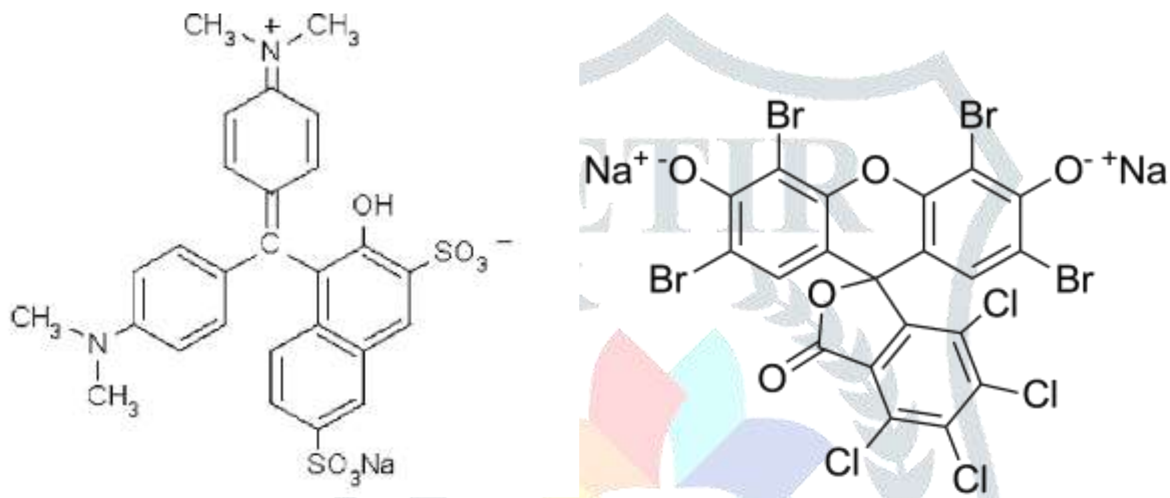

Figure 1: Chemical Structure of (a)Lassamine Green (b)Phloxin B

Materials

Conductive glass plates, specifically fluorine-doped tin oxide (FTO) glass with a sheet resistance of 7 ohms per square centimeter, served as substrates for the deposition of porous titanium dioxide (TiO_2) films. These glass plates were cut into 1 cm^2 squares. All chemicals and solvents used were of analytical grade and employed without further purification.

Preparation of TiO_2 electrode

To prepare a uniform TiO_2 paste, a specific amount of TiO_2 powder was mixed with acetic acid and ethanol. This mixture was continuously stirred for an hour, followed by the addition of ethanol to improve homogeneity and granularity. A few drops of Triton-X 100 were added to enhance colloidal behavior, nanoparticle dispersion, and paste smoothness, ensuring a 10-12 micrometer thick TiO_2 layer on the FTO glass plate. Subsequently, HCl/HNO_3 was added to adjust the pH to 3-4. The paste was then heated for 30 minutes. To prepare the TiO_2 electrode, the FTO plate was immersed in a dye solution for 24 hours.

Preparation of counter electrode

The cathode was fabricated by depositing a chloroplatinic acid solution onto an FTO glass substrate. To prepare the counter electrode solution, 2 milliliters of chloroplatinic acid was dissolved in a propanol solution.

DSSC fabrication

A small droplet of electrolyte solution was applied to the dye-sensitized TiO_2-coated working electrode (anode). The counter electrode, typically a platinum-coated conductive glass, was carefully placed on top of the working electrode, ensuring the conductive side faced the dye-sensitized TiO_2 layer. To prevent electrolyte leakage and maintain long-term stability and efficiency, the cell's edges were sealed.

III. RESULTS AND DISCUSSION

Powder XRD analysis

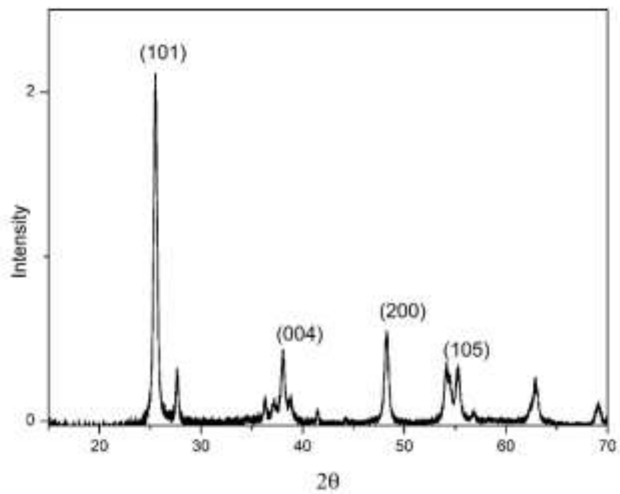

Figure 2: XRD pattern of grinded nano-particles of TiO_2 powder

TiO_2 nanoparticles were subjected to powder X-ray diffraction (PXRD) analysis in order to ascertain their structure and size. The PXRD pattern of pure TiO_2, as seen in Figure 2, has a single diffraction peak that is suggestive of a crystalline structure. The production of nanocrystalline anatase TiO_2 is confirmed by the existence of distinctive diffraction peaks at (101), (004), and (200).

Scanning Electron Microscope (SEM) studies:

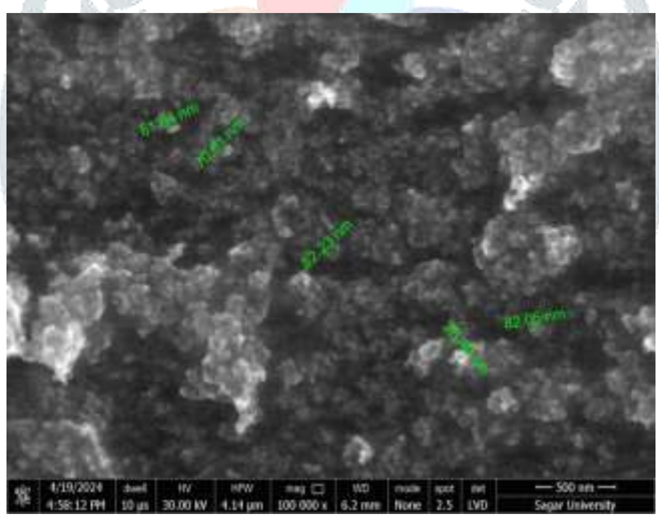

Figure 3: SEM images of TiO_2 at 100K X magnification

The scanning electron microscope (SEM) image of pure TiO_2 nanoparticles synthesized by sol gel method in Fig 3. The pure TiO_2 nanoparticles have agglomerated together toform lots of nanoclusters. These nanoclusters will affect the photoelectric behavior of TiO_2. Surfactants or capping agents are frequently used to increase particle dispersion and lessen this problem.

Optical parameters of dye :

The optical properties of the photosensitizer were examined using a SYSTRONICS DOUBLE BEAM UV-Visible Spectrophotometer 2202 within a wavelength range of 200 to 800 nanometers. Diverse spectra were recorded, exhibiting distinct maximum absorption wavelengths (λ_{max}) in various solvents.

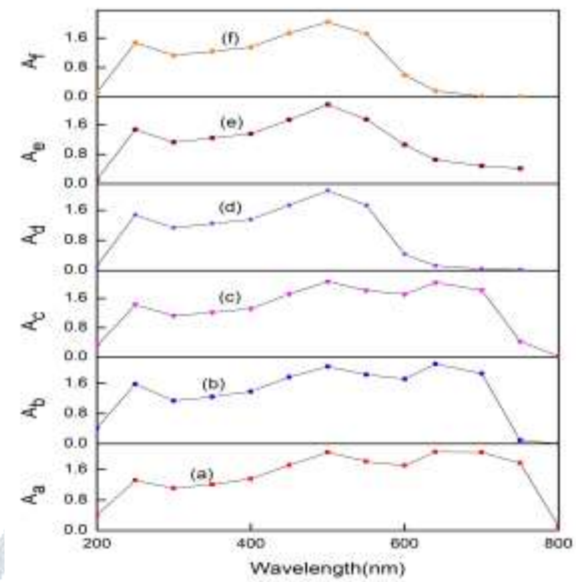

Figure 4: comparative UV- Visible absorbance curve of both sensitizersin various solvents: (a) LG in NMP (b) LG in ethanol (c) LG in DMSO (d) PB in NMP (e) PB in ethanol (f) PB in DMSO

Electrochemical parameters of DSSC :

The fabricated DSSCs were assessed for their voltage and current output using a variable load resistor. Under standard AM 1.5G illumination (100 mW/cm²), the open-circuit voltage (V_{OC}) and short-circuit current (i_{SC}) were measured. These values were used to construct an i-V curve, from which crucial parameters like maximum power point current (i_{PP}), maximum power point voltage (V_{PP}), maximum power output (P_{max}), fill factor (FF), and energy conversion efficiency (η) were determined. The experiment aimed to optimize the dye's light-to-electricity conversion efficiency, leading to improvements in both i_{SC} and V_{OC}.

$$\text{Fill Factor(FF)} = \frac{V_{PP} \times i_{PP}}{V_{OC} \times i_{SC}}$$

$$\text{Conversion Efficiency}(\eta) = \frac{i_{sc} \times V_{oc} \times FF}{P_{input}} \times 100\%$$

Electrochemical parameters power conversion efficiency and fill factor of DSSCs can be calculated using above expression.

Table 1

Electrochemical parameters of DSSC fabricated with dye extracts in using various solvents

Dye	Solvents	V_{oc}(mV)	i_{sc}(mA)	FF	η (%)
Lassamine Green	NMP	1654	1.682	0.66	1.852
	Ethanol	1990	1.163	0.31	1.185
	DMSO	1907	1.989	0.58	2.23
Phloxin B	NMP	1381	1.611	0.54	1.206
	Ethanol	1688	1.858	0.46	1.47
	DMSO	1647	1.812	0.53	1.57

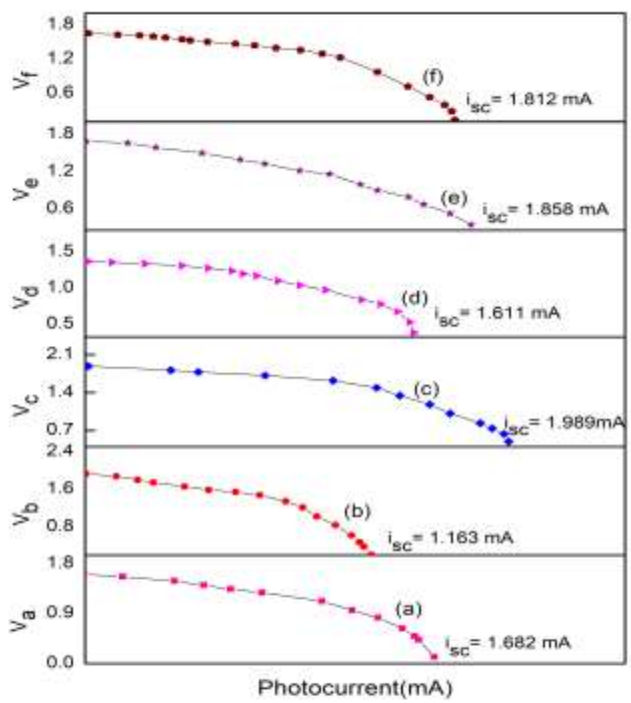

Figure 5: Comparative (i-V) characteristics of both sensitizers in various solvents: (a) LG in NMP (b) LG in ethanol (c) LG in DMSO (d) PB in NMP (e) PB in ethanol (f) PB in DMSO

IV. CONCLUSIONS

X-ray diffraction (XRD) analysis confirmed the anatase phase of TiO_2 nanoparticles calcined at 250 degrees Celsius. The fabricated DSSCs exhibited light-to-electron conversion efficiencies ranging from 1.1 to 2.2%. In N-methyl-2-pyrrolidone (NMP) and dimethyl sulfoxide (DMSO) solvents, lassamine green demonstrated higher efficiency (1.852% and 2.23%) compared to phloxin B. In contrast, phloxin B exhibited highest efficiency (1.47%) in ethanol. DMSO proved to be an effective solvent for both sensitizers, as both lassamine green and phloxin B achieved their highest efficiencies of 2.23% and 1.57%, respectively, in DMSO.

V. ACKNOWLEDGEMENT

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