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A Study on Fabrication and Application of Plant-based Dyes in Dye-Sensitized Solar Cell (DSSC)

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ABSTRACT: DSSCs are researched extensively due to their low cost, ease of fabrication, and environmental sustainability. This study focuses on the fabrication and application of plant-based dyes as sensitizers in DSSCs, aiming to explore their potential for improving the efficiency and affordability of solar energy conversion.

KEYWORDS: DSSC, plant, dye and fabrication.

I. INTRODUCTION

The Asian region encounters substantial energy issues, as energy demand is projected to nearly double by 2030. These matters are affected by sustainability, economic development and geopolitical factors. The total installed renewable energy capacity in India, measured in megawatts, has seen significant growth, predominantly driven by hydroelectric power facilities. Wind power generation in India mostly derives from installed capacity, with the second greatest contribution to renewable energy experiencing exponential growth. By 2040, China and India will account for the majority of global energy use, influencing both energy dynamics and environmental conditions. Priority action plans are directed by digitization, electrification and decarbonization. India's commitment to development persists; yet, it confronts many uncertainties, including extreme weather concerns, complications in the Middle East and climate frameworks. India needs to prioritize energy efficiency, energy subsidies, economic development, mobile cloud technology and national progress. Also, India must prioritize energy conservation and renewable energy sources, diversify its import portfolio, and expand its energy supply sources. India's emphasis on energy conservation and renewable energy is essential because of its significant dependence on oil and gas imports. Trends in the Middle East are perceived to exhibit heightened influence and unpredictability, with events like as US sanctions on Iran and disruptions to Saudi Arabian oil infrastructure impacting Indian energy executives. To attain the 100% renewable energy objective outlined in Vision 2015, India must consider energy efficiency, energy subsidies, economic development, and national progress. India today confronts significant uncertainty regarding regional integration, US policy, and market design.

In India, the energy transition is intricately connected to long-term objectives, including poverty reduction and environmental and climatic issues. The projected expansion in demand for commercial energy sources serves as a significant motivator for facilitating energy transition. To achieve the low carbon scenario, India must invest in sophisticated energy technology to mitigate potential carbon emissions resulting from increased reliance on fossil fuels. India needs around $694 billion from 2021 to 2030 to mitigate total carbon dioxide emissions of 1,167 Mt CO_2. India's population, projected to reside below the poverty line, is anticipated to witness a potential increase in energy consumption in the forthcoming years as the economy strives for double-digit growth. This underscores the necessity for India's policy focus to ensure sufficient energy supply from all available sources to fulfill the increasing demand.

The growing global energy demand, coupled with the environmental challenges posed by fossil fuel consumption, has underscored the urgent need for renewable energy sources. Solar energy, being abundant, clean, and inexhaustible, has emerged as a vital solution to address the energy crisis and mitigate climate change. Harnessing solar energy through photovoltaic technologies reduces greenhouse gas emissions and dependence on finite natural resources, aligning with the goals of energy security and environmental sustainability. However, conventional silicon-based solar cells, while efficient, involve high production costs, energy-intensive manufacturing processes, and limited flexibility, making them less accessible for widespread adoption. These challenges have prompted researchers to explore alternative photovoltaic technologies that are cost-effective, environmentally friendly, and easier to fabricate. Among these alternatives, DSSCs have garnered significant attention due to their unique combination of affordability, simplicity, and versatility. DSSCs offer several advantages over traditional photovoltaic systems. They utilize a broad range of light wavelengths, allowing effective energy conversion even under low-light conditions. The modular design of DSSCs

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enables their integration into various applications, including flexible and transparent surfaces. Moreover, the use of natural or synthetic dyes as light-harvesting agents reduces the dependency on rare or expensive materials, further enhancing their cost-effectiveness.

II. ORGANIC DYES AND THEIR APPLICATION IN DSSCS

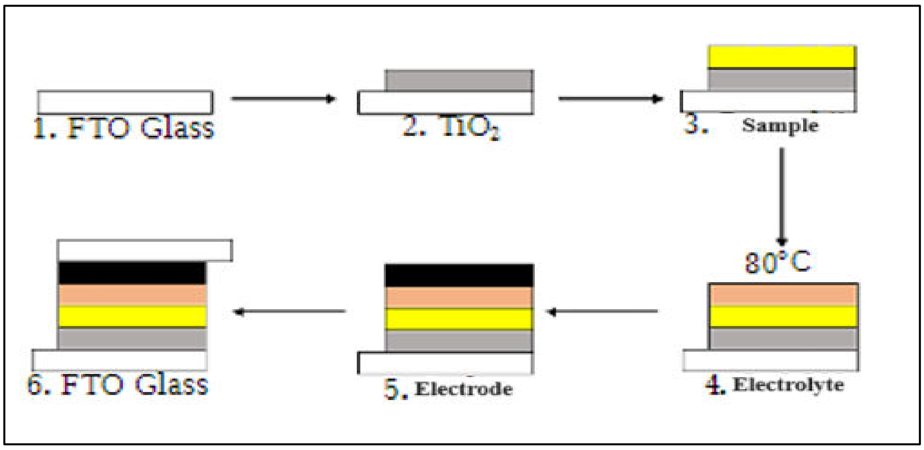
The operation of solar cells is predicated on the transformation of solar energy into usable energy, directly transforming sunlight into electricity. DSSCs were initially available in 1991 and have garnered significant interest from researchers due to their affordability, simplicity, efficiency, adaptability, and translucence. Dyes can be derived from diverse sources, including flower petals, leaves, and roots, manifesting as anthocyanins, chlorophyll, flavonoids, and carotenoids. Organometallic dyes, like Ruthenium dyes, are crucial for producing DSSCs with high efficiency; yet, they are costly and challenging to purify in comparison to natural dyes. The transformation of sunlight into electricity relies on photo-sensitization. DSSCs function as effective solar cells constructed from different nanostructured films of metal oxides, including ZnO, SnO_2, $SrTiO_3$, Ta_2O_5, and WO_3. The operation of DSSCs entails multiple processes, commencing with the application of a thin layer of semiconductor oxide, such as TiO_2, ZnO, or SnO_2, onto a designated glass substrate. The third generation of solar cells, termed DSSCs, transform visible light into electricity via photo-electrochemical reactions. This configuration features a sandwich construction including a semiconductor situated between a photo-sensitized anode and an electrolyte. Natural dyes, generally organic compounds, are seen superior due to their cost-effectiveness, solubility in water, accessibility, and biodegradability.

Natural dyes are categorized into three classifications: plant-based, animal-derived, and mineral-based. Natural dyes can serve as sensitizers in solar cells, photoelectrodes, and for the pigmentation of hair, skin, and textiles. A comparison of natural dye versus synthetic dye solar cells is predicated on several characteristics, including cost, stability, absorbance, environmental impact, resource utilization, cell efficiency, and the manufacturing techniques employed. Natural sensitizers are typically obtained using extraction procedures from plants, flowers, fruits, and roots, utilizing ethanol, water, or methanol as solvents. This renders them more economical in comparison to synthetic dyes. It is crucial to minimize charge recombination between the oxidized sensitizer and the injected electrons in TiO_2, inhibit coordination between the sensitizer and iodide, and ensure optimal overlap of the LUMO with the TiO_2 surface. Synthetic dyes possess numerous drawbacks, including reduced environmental impact attributable to their chemical composition, susceptibility to degradation under sunlight, stability issues and absorption bands within the visible spectrum (400–700 nm). The absorption spectra of dye solutions extracted from Cytisus, Alcea rosea, and Roselle, as well as the dye materials applied to TiO_2 films, are presented in the region of 400–700 nm. Hence, the production process, purifying techniques, and accessibility of natural dyes must be meticulously evaluated to optimize their efficacy.

III. FABRICATION OF DSSC USING PLANT BASED DYES

A variety of dye sensitizer complex systems are synthesized and analyzed their potential use in DSSCs. The study used following photosensitizers: Phyllanthus urinaria (Quercetin 7-Methyl Ether), Berberis asiatica (Berberine) and Cassia bakeriana (Epicatechin).

Fig 1: Fabrication of Solar Cell



The fabrication of solar cell with synthesized dye involved the following procedure: 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 ºC 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.

The performance of solar cells was evaluated using natural plant-based dyes.

Table 1: Observation Table

Dyes	V_{oc}	I_{sc}	Solar Irradiance	Fill Factor	Efficiency (%)
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

The study 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. 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.

IV. CONCLUSION

The study's findings highlight the potential of natural plant-based dyes as efficient sensitizers for DSSCs. Both Berberis asiatica and Phyllanthus urinaria performed well 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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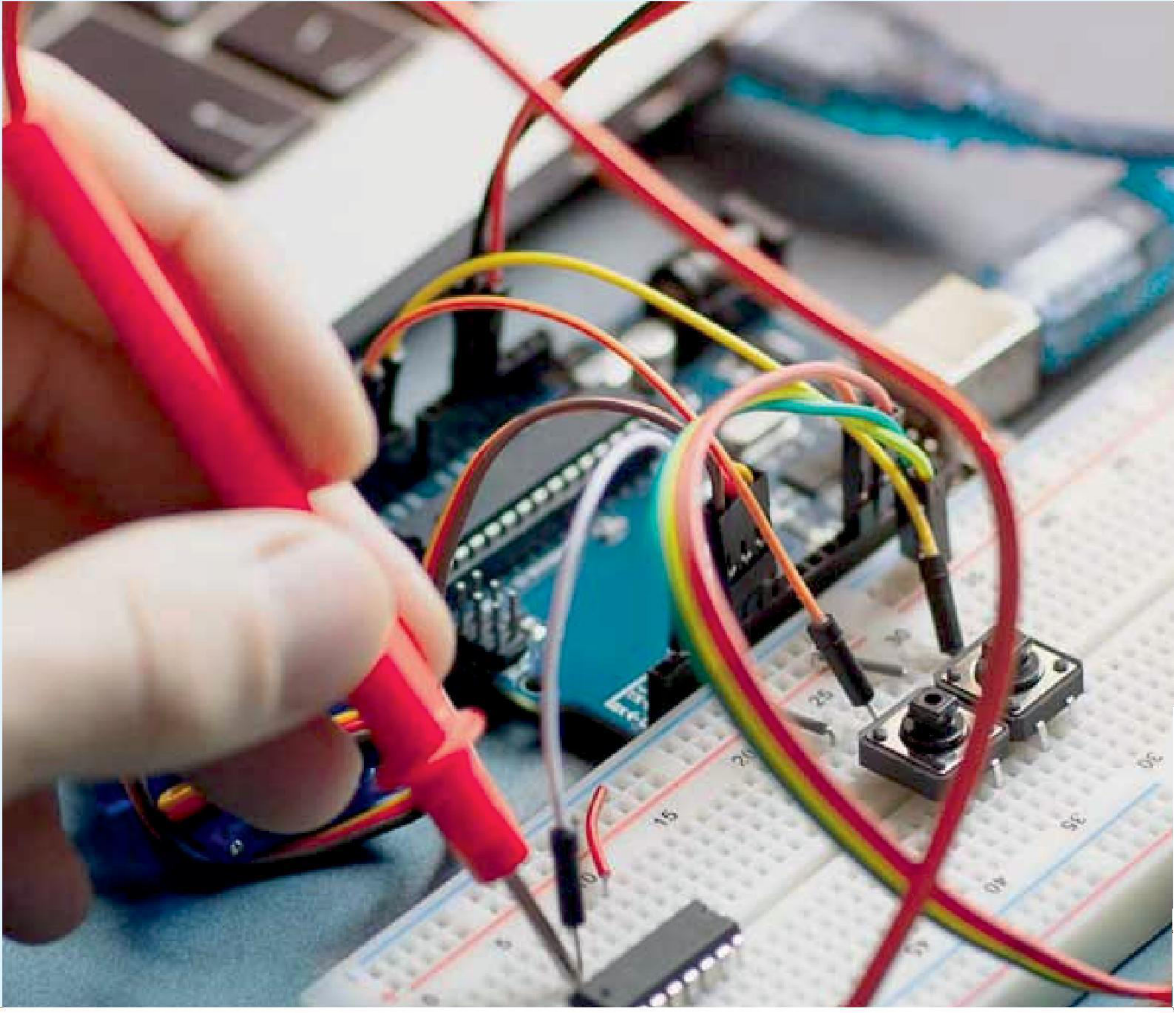

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