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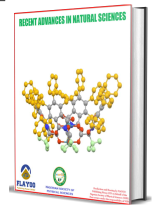

Fabrication and characterization of dye-sensitized solar cells using *Allium cepa* flower extract as a means of harnessing the solar energy

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ABSTRACT

Climate change and global warming have spurred a growing urgency to transition from traditional energy sources to sustainable alternatives. This article explores the realm of renewable energy, focusing on the potential of dye-sensitized solar cells (DSSCs) as an eco-friendly solution. The study examines the efficiency of a DSSC utilizing a dye extract from *Allium cepa* (onion) flowers, shedding light on the material's viability as a photosensitizer. The article covers the physics of solar cells, the operation principle of DSSCs, and the specific components involved in fabricating a DSSC based on *Allium cepa* extract. The findings show that the extract obtained from *Allium cepa* flower exhibited maximum absorbance of 1.4793 at a wavelength of 437.74 nm in the visible region of the electromagnetic spectrum. And when adsorbed on the TiO_2 semiconductor surface, the absorbance of the sample increased to the value of 1.5189 at a wavelength of 423.89 nm in the visible region. The energy bandgap of 4.21 eV was obtained for *Allium cepa* extract. The fill factor of 0.61 was obtained, and a light conversion efficiency of 0.43 % was achieved. With these results, the dye extract obtained from dry *Allium cepa* flowers is a good photosensitizer for making dye-sensitized solar cells.

1. INTRODUCTION

The effects of climate change and global warming are becoming severe every day due to the continuous use of energy derived from petroleum sources. As a result, there is a need to diversify into other alternative sources of energy and power. The use of renewable energy sources has gained a large popularity as it is always available. Renewable energy refers to all forms of energy that can replenish their selves over a period of time. Examples of renewable energy are solar energy, wind, and hydro energy. Devices that can convert solar energy into electricity are called solar cells. These devices are usually made from semiconductor materials with a wide bandgap and do absorb light in the ultraviolet region, visible region, and infrared region of the electromagnetic (EM) spectrum [1]. Dye-sensitized solar cells (DSSCs) are one of such devices that can absorb sunlight and convert it into electricity. A typical DSSC consists of a dye, a photoanode, a cathode, and an electrolyte [2]. Dye sensitized solar cells have arisen as a chemically and economically credible alternative [3] to P–N

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junction photovoltaic devices in the late 1960s. It was discovered that electricity can be generated through illuminated organic dye molecules in electrochemical cells. Chlorophyll-sensitized zinc oxide (ZnO) electrode came into the limelight through synthesis in 1972 for the first time through electroinjection of excited dye molecules into the wide band gap of the semiconductor. Protons were converted into electricity. At the University of California at Berkeley, chlorophyll was extracted from spinach, but the efficiency of the dye-sensitized solar cell was very poor as the monolayer of the molecule was able to absorb incident light only up to one percent. A solar cell, also called a photovoltaic cell, is any device that absorbs free electrons or photons of light and directly converts them into electrical energy through the photoelectric effect. According to Ellis [4], this phenomenon is known as photovoltaic and occurs at the atomic level. Solar cells are made from the same kind of semiconductor materials as silicon, which are used in the microelectronics industry. For these cells, if an electric conductor is attached to both terminals of the cell, forming an electric circuit, electrons can be captured as electrical current (that is, electricity). Dye-sensitized solar cells made from synthetic dyes such as Ruthenium have high light conversion efficiencies, but it is very expensive and also toxic to humans. Dye-sensitized solar cell technology has become very popular in recent years, with a large volume of research aimed at improving the effectiveness of these categories of solar cells.

Looking into the importance of DSSCs in the harnessing of solar power, various researchers have carried out studies on various natural dyes [5–10] and revealed that DSSCs can improve the green environment and its sustainability as they help to solve the problem of global warming. In the study done by Al-Kahlout *et al*. [5] on the comparative study of synthetic dyes as photosensitizers for DSSCs using ZnO semiconductor layer and different synthetic dyes, a conversion efficiency of 5.61% was obtained. Also, an optimization study of the cell, which involves the spiro-OMETAD and perovskites thickness, affects the electrical output parameter of the fabricated cell [11].

In a comparative study of the efficiency of dye sensitized solar cells examined by various researchers [6, 12–15], natural dyes show that the presence of anthocyanin, carotenoids, and flavonoids, which are the bases for the pigmentation and subsequent phytochemicals, which are mostly useful in textile dyeing due to this property and the potential use as a sensitizers for solar energy collection. In the study of Bristi *et al*. [15], the solar cells fabrication employed several natural dyes as sensitizers and adsorbed on titanium dioxide (TiO_2), which served as the semiconductor layer. The DSSC based on *Curcuma Longa* performed the highest Voc of 0.5959V and Jsc of 1.60mA/cm^2 with an optimum light absorbance between wavelengths of 380 nm to 400 nm. TiO_2 is an important dopant for DSSCs due to its bandgap [6, 7]. Some new research on dye-sensitized solar cells focuses on improving performance and stability by developing and introducing new natural dyes as sensitizers, enhancing components like the photoanode and electrolyte, and using nanomaterials [16–18]. Innovations include using metal-free organic dyes, optimizing natural dyes, and incorporating nanomaterials like PEDOT-coated carbon nanofibers into counter electrodes to boost conductivity and durability. Efforts to overcome recombination issues and increase light absorption are key drivers for these advancements.

Hence, this research is set to study the DSSCs' efficiency, based on *Allium cepa* extract. DSSCs have proven to be very vital over the course of time for the harnessing of solar energy, with the significance of cost effectiveness, easily fabricated from raw materials, readily available, performs well under high temperatures with diffuse light conditions, and devices fabricated with DSSCs are void of noise and environmental pollution.

2. MATERIALS AND METHODS

The following materials and reagents were utilized in the course of this research. Dry *Allium cepa* flowers, Ethanol, Water, Digital balance, Measuring cylinder, Laboratory mortar, FTO conducting glass substrate, Iodolyte N50 (electrolyte), Titanium diode paste, Platinum paste, Spectrophotometer, Whitman filter paper, Centrifuge, Test tubes, Petri dish, etc.

The transparent conductive oxide-coated glass was used as a substrate for both the photo-anode and counter electrode. The coating of this layer is required for the collection of electrons ejected from the photo-anode (dye-coated TiO_2) and passing them to the counter electrode through the outer circuit.

2.1. CURRENT–VOLTAGE SIMULATION

This measurement is carried out on the fabricated solar cell. It is the most important measurement of a solar cell done to obtain the electrical parameters of the cell with the help of a J-V characteristics curve. This measurement is achieved under an illumination with a similar spectrum to air mass (A.M) 1.5 and light intensity of 100 mW/cm^2. The basic photo electrochemical parameters include: open circuit voltage (Voc), short circuit voltage (Isc), fill factor (FF), and efficiency (η). These parameters can easily be obtained from the graph, as well as the use of relevant equations.

2.2. FILL FACTOR (FF)

This is a key factor in evaluating the performance of a DSSC. It describes the square-ness of the J-V curve and the electrical losses during the operation of the cell. In general, the fill factor is the ratio of the maximum power (P_{max}) obtained from the cell and the incident light to the theoretical power.

$$FF = \frac{P_{\max}}{J_{sc} \cdot V_{oc}}. \tag{1}$$

2.3. EFFICIENCY

It is the ratio of output power and the incident light intensity (P_{in}) is numerically equal to 100mW/cm^2.

$$\eta = \frac{P_{\max}}{P_{in}} \times 100. \tag{2}$$

Alternatively,

$$\eta = \frac{J_{sc} \times V_{oc} \times FF}{P_{in}}. \tag{3}$$

2.4. EXTRACTION SOLVENT

In this study, the dye extraction solvent used consists of a mixture of ethanol and distilled water. The solvent content is 70% ethanol and 30% distilled water.

2.5. EXTRACTION OF DYE SENSITIZER FROM *Allium cepa* FLOWER

The dye from the dry *Allium cepa* flower was extracted using a physical extraction method. The following procedures were followed;

- Using a digital balance, the total weight of *Allium cepa* flower was measured to be 1.34g, out of which 1.00g of the flower was put into a laboratory mortar and properly crushed.
- 20ml of the solvent was then added and vigorously mixed.
- The mixture was filtered into a test tube using the Whitman filter paper. The extract was then subjected to centrifugation at 2500 revolutions per minute to remove tiny particles.

2.6. PREPARATION OF PHOTO ANODE AND CATHODE

The photoanode and cathode (counter electrode) were prepared using the screen printing method or technique. Fluorine-doped tin oxide (FTO) conducting glass substrate was properly cleaned using ethanol and allowed to dry. An active area of 0.25cm^2 was mapped out using masking tape. Thereafter, TiO_2 paste was screen printed on an active area with the help of a squeegee and then heated to a certain degree Celsius so that all other elements present in the paste are burnt out, leaving the TiO_2 semiconductor in its pure and compact form. After cooling, it was treated with titanium tetrachloride ($TiCl_4$) solution for 30 mins. Then it was later immersed in the dye extract overnight to ensure proper discoloration. The cathode, also known as the counter electrode, was also prepared by screen printing platinum paste (Platisol T/SP Solaronix) on the same active area and then heated and allowed to cool.

2.7. SOLAR CELL ASSEMBLY

The photoanode and cathode were put together to overlap each other along the active area to form a sandwich form of arrangement and sealed using a glue called Meltonix, and then the electrolyte (iodolyte N50) was introduced from the edge of the cell using a syringe. The electrolyte gently spread over the entire surface of the active area of the fabricated solar cell.

2.8. TESTING

The current–voltage simulation was done using Oriel Class A solar simulator under solar light intensity of 100 mW/cm^2 and A.M 1.5 Spectrum. The current–voltage results obtained for the fabricated solar cell are presented bellow.

3. RESULTS AND DISCUSSION

3.1. ABSORBANCE RESULTS

The optical characterization was employed to measure the light absorption of the dye sensitizer as well as that of the photo anode using a spectrophotometer (UV-750 Series) from wavelength range of 230 nm to 1100 nm. These absorbance results are presented below.

Figure 1 shows absorption spectra of *Allium cepa* extract, as revealed in the figure that the maximum absorbance peak (~1.5–1.6 a.u.) of the cell is in the wavelength range of 430nm to 480nm, which happened to be the strong absorption in the UV–visible region. The spectrum shows a sharp rise in absorbance starting around 300 nm, indicating that the *Allium cepa* extract strongly absorbs UV light.

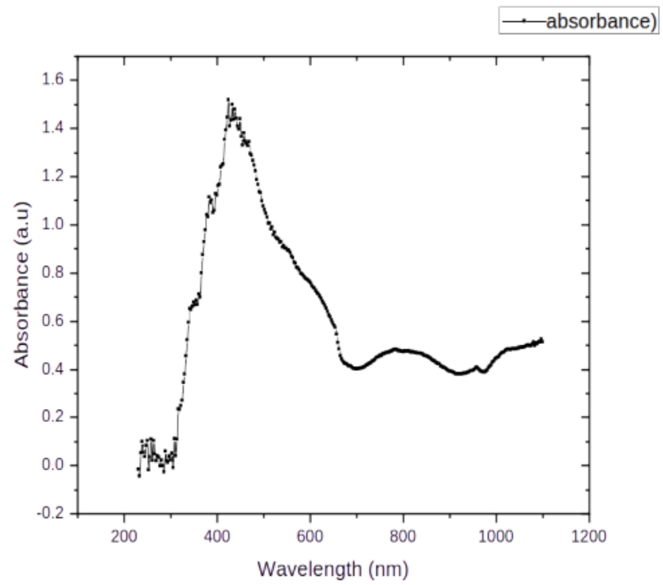

Figure 1. Absorption spectra of *Allium cepa* extract adsorbed on TiO_2 surface.

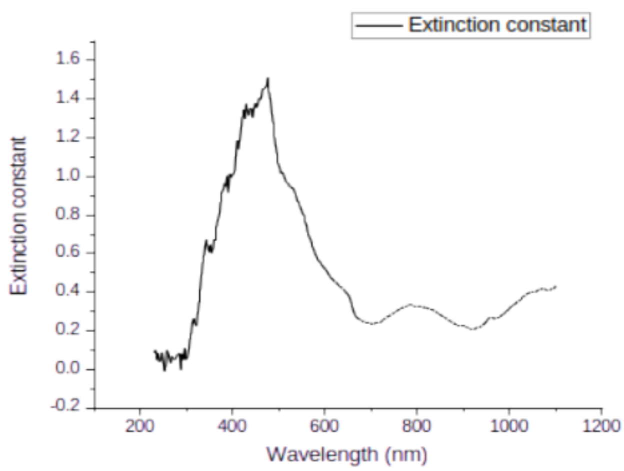

Figure 2. Extinction constant spectra against wavelength.

Figure 2 shows the graph of extinction constant with wavelength which revealed that the extract obtained from *Allium cepa* flower exhibit maximum extinction constant of 1.50 at the wavelength of 490 nm. The extinction constant of the *Allium cepa* flower has a high value of 300-490nm wavelength as the peaks which is the ultraviolet region of the EM spectrum. In Figure 2, extinction constant of *Allium cepa* is minimum at about 300 nm to 490nm, the infrared region of the EM spectrum.

The absorption of light by the thin film was observed mostly in the ultraviolet region and their absorbance reduces as you move from ultraviolet to the visible and infrared region of the EM spectrum. This revealed that the *Allium cepa* thin film can be used for the coating of surfaces in order to absorb the ultraviolet region

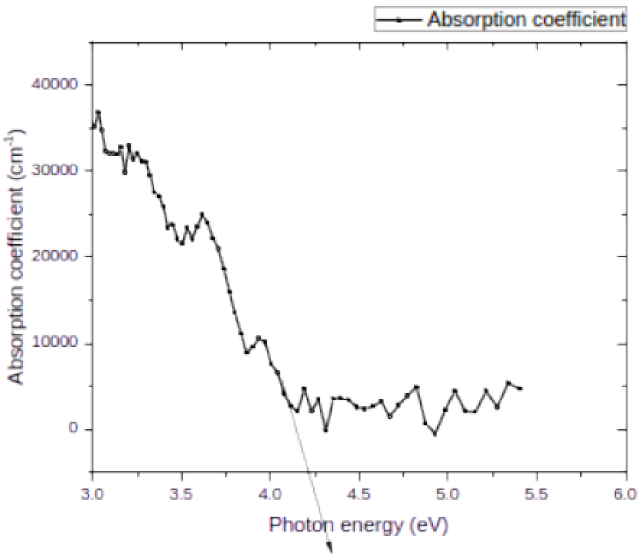

Figure 3. Energy band gap of *Allium cepa* extract.

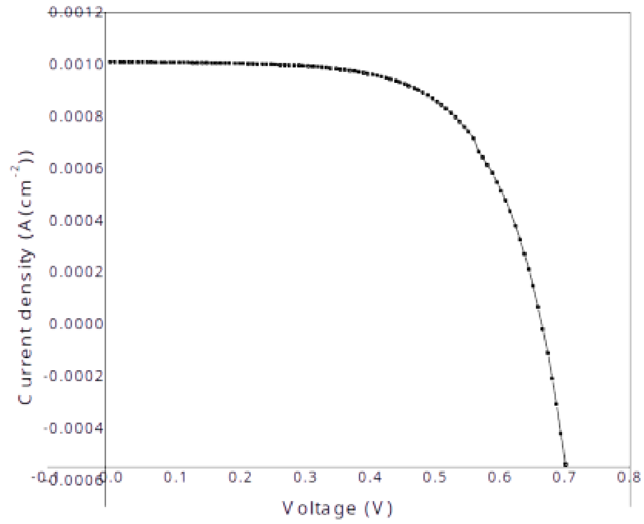

Figure 4. J-V characteristics curve of the DSSC fabricated using *Allium cepa* extract.

of the EM spectrum.

The extract obtained from *Allium cepa* flower exhibited maximum absorbance of 1.4793 at a wavelength of 437.74 nm in the visible region of the EM spectrum.

When adsorbed on TiO_2 semiconductor surface, the absorbance of the sample increased to the value of 1.5189 at wavelength of 423.89 nm in the visible region. The samples also showed sign of light absorption across the infrared region of the EM spectrum.

Figure 3 shows an energy band gap of 4.21 eV obtained for *Allium cepa* extract for the absorption coefficient versus photon energy. This shows consistency with what is expected for many natural dyes, which often have bandgaps in the 3-5 eV range. This bandgap recorded implied that the dye absorbs mainly in the UV region, not the visible region. This shows wide bandgap energy for *Allium cepa* extract. The absorption coefficient is very high (approximately 35,000 to 40,000cm^{-1}) at photon energies around 3.0-3.3 eV. This shows strong absorption in the UV region, meaning the extract absorbs UV photons efficiently but may require sensitization or modification to absorb visible light effectively.

The graph as shown in Figure 4 is current density (J) plotted against voltage (V) for the dye-sensitized solar cell made with *Allium cepa* extract. This curve is essential for evaluating the photovoltaic performance of the DSSC. At 0 V, the current density is approximately 0.010 A cm^{-2} (10 mA cm^{-2}). This value represents the maximum photocurrent generated when the circuit is shorted. The curve meets the voltage axis near 0.68–0.70 V. This point is the open-circuit voltage, representing the maximum voltage the cell can generate with no current flow. The thin film demonstrates the potential of onion extract as a natural sensitizer, although optimization is needed for improved fill factor and overall power conversion efficiency.

Figure 5 shows how the absorption coefficient varies with wavelength (200–1200 nm) for the *Allium cepa* dye. This spectrum is crucial for understanding how efficiently the material

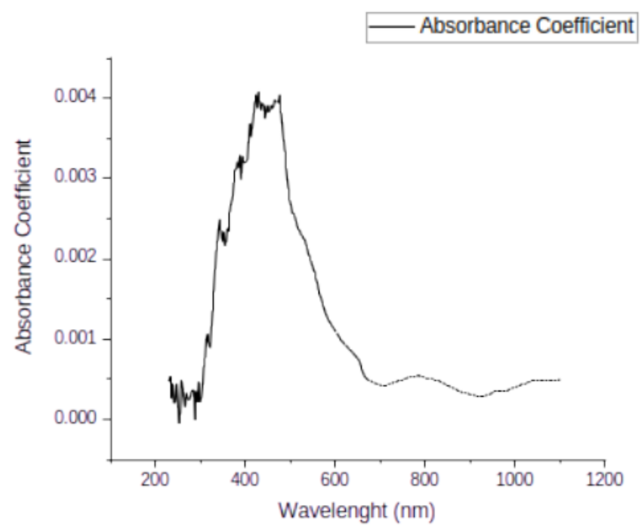

Figure 5. Absorption coefficient spectra against wavelength.

absorbs light across the UV–visible–NIR regions of the electromagnetic spectrum. The absorption coefficient is very low (0 -0.0003) at wavelengths below 300 nm. A small rise appears around 300–350 nm, suggesting a weak absorption in the deep UV region. A sharp increase begins around 350–380 nm, showing the onset of strong absorption. The absorption coefficient peaks at approximately 0.004 around 450–480 nm. The absorption coefficient spectrum shows a dominant absorption peak in the 350–500 nm region, with a maximum around 450–480 nm, indicating strong electronic transitions and efficient photon absorption in the UV-blue range. Absorption decreases significantly beyond 500 nm, with very weak activity in the red and near-infrared regions. This behavior suggests that the material is most effective at harvesting high-energy photons, making it suitable for DSSC applications where UV-blue absorption is essential, though its limited visible/NIR absorption may constrain

Table 1. Electrical parameters showing fabricated dye-sensitized solar cell.

Dye source	J_{sc} (mA/cm^2)	V_{oc} (V)	P_{max} (mW)	Fill factor	Efficiency (%)
Allium cepa	1009	0.6998	0.1075	0.61	0.43

overall photocurrent generation.

From the J-V characteristic curve, in Figure 4, the electrochemical parameters of the solar cell sensitized with *Allium cepa* extract are summarized in Table 1:

Table 1 shows that the *Allium cepa* dye-sensitized solar cell exhibits a moderate voltage (0.7 V) and reasonable current density (1009 mA/cm^2), but a low overall efficiency (0.43%) due to limited light absorption range and possible charge recombination losses inherent to natural dyes. This implies that while *Allium cepa* based dye can generate measurable photovoltaic activity, further optimization (e.g., co-sensitization, dye purification, TiO_2 surface modification, or electrolyte tuning) is needed to enhance the performance of such eco-friendly DSSCs.

4. CONCLUSION

In this study, a dye-sensitized solar cell was successfully fabricated using dye extracted from dried *Allium cepa* flower as a sensitizer. The absorbance of the dye and also that of the anode were measured with a UV/Vis spectrophotometer from wavelength of 230 nm to 1100 nm. The results showed the maximum light absorption of light in the visible region of the EM spectrum. A broad absorption was also noticed across the infrared region as the wavelength increases. The energy band gap of 4.21eV was obtained from the graph of absorption coefficient against photon energy by way of extrapolation. The fill factor of 0.61 was obtained and light conversion efficiency of 0.43 % was achieved. With these results, the dye extract gotten from dry *Allium cepa* flower is a good photosensitizer for making dye-sensitized solar cells. We observed that *Allium cepa* dye solar cell exhibits a moderate voltage of 0.7 V and a current density of 1009 mA/cm^2 and an efficiency of 0.43%. With this findings it is recommended that while *Allium cepa* based dye can generate measurable photovoltaic activity, further optimization such as co-sensitization, dye purification, TiO_2 surface modification, or electrolyte tuning is recommended to enhance better performance.

DATA AVAILABILITY STATEMENT

The data generated and analyzed during the current study are available from the corresponding author on reasonable request.

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