Original article

Enhancement of Quantum Efficiency of A Dye-Sensitized Electrochemical Cell by using Triturated Zinc Oxide Mixed with Two Organic Dyes, Azure C and Rose Bengal

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Abstract

For efficiently utilising solar energy, when suitable nanoparticles are being engineered, triturated zinc oxide an eco-friendly, easily available, low-cost material has been used as an agent for solar energy conversion. Two organic dyes Azure C and Rose bengal having absorption bands in two different spectral regions at 545 nm and 610 nm respectively, were chosen in order to overcome the band absorption limits of each dye and utilise the broad spectrum of solar radiation. The material was mixed with these two dyes in a specially devised electrochemical cell and photovoltage with significant efficiency was generated. The energy conversion efficiency of the cell using three different potencies 6C, 30C and 200C of triturated zinc oxide with the same concentration of two dyes (0.5×10^{-5} M) in all cases are 0.39%, 0.43% and 0.35% respectively. The efficiency is only 0.15% for the mixed dye under similar conditions.

Keywords: Energy conversion efficiency, electrochemical cell, mixed dyes, triturated zinc oxide, adsorption.

Introduction

Mankind faces a great energy challenge due to the depletion of fossil fuels at an alarming rate with exponential increase in population and growing demand for the modern lifestyle. To overcome this situation, utilisation of omnipresent and abundant solar energy has become the most promising one. Conventional silicon technology based photovoltaics has its own limitations. So research on developing new and novel materials for conversion of solar

energy into electrical energy with high efficiency is emphasised. Many photosensitive dyes are being used for such conversion.¹⁻²

The invention of nanoparticles, which possess the unique chemical and physical properties with size and shape variations, has a strong impact in photovoltaic technology as they can facilitate the conversion process of solar energy to electrical energy.³⁻¹¹

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For designing new and more effective light energy harvesting devices in cost effective way, several nanomaterials have been synthesised. Amongst them, TiO_2 , ZnO , SnO_2 are the maximum utilised nanomaterials due to their proper physical and chemical properties.¹²⁻¹⁴

While searching for novel and suitable materials, the idea of utilisation of the nanoparticle aspect of triturerated zinc oxide (ZnO) has been explored.¹⁵ This material is in the true sense a quite innovative one for use as an agent for solar energy conversion. To ensure the performance of the electrochemical cell over a broad solar spectrum range, two dyes Azure C and Rose bengal, having absorption bands in two different spectral regions 545 nm and 610 nm respectively, were chosen in order to overcome the band absorption limits of each dye and were combined together.

Our result shows that photo-induced voltage with significant efficiency is generated when triturerated ZnO is used in combination of these two different photosensitive organic dyes in a specially devised electrochemical cell. The energy conversion efficiency of the cell using three different potencies 6C, 30C and 200C of triturerated zinc oxide with a same concentration of the two dyes (0.5×10^{-5} M) in all cases are 0.39%, 0.43% and 0.35% respectively. The efficiency is only 0.15% for the mixed dye under similar conditions.

Materials & experimental method

A. Materials

Freshly prepared triturerated ZnO of three potencies (6C, 30C and 200C) were obtained from Hahnemann Publishing Company, India. The dyes Azure C

($\text{C}_{13}\text{H}_{12}\text{ClN}_3\text{S}$) and Rose bengal ($\text{C}_{20}\text{H}_4\text{Cl}_4\text{I}_4\text{O}_5$) were purchased from Loba Chemie, Mumbai, India and were used without further purification.

B. Methods

Preparation of Azure C – Rose bengal-triturerated ZnO system:

The stock solutions of Azure C and Rose bengal were prepared by dispersing them in water. The final concentration of the solutions was 0.5×10^{-5} M. For UV-VIS spectral study and photovoltage generation, desired concentration of Azure C and Rose bengal mixed solutions were prepared by further diluting the stock solutions. Triturerated ZnO of specific potency was mixed with a certain concentration of dye solution ($0.85 \mu\text{M}$) in 1:5 volume ratios.

C. Photovoltage generation study:

Photovoltage generation was recorded for potency 6C, 30C and 200C in a specially devised electrochemical (EC) cell (Figure I).

Figure-I: Schematic diagram of the photoelectrochemical cell; A & B – Platinum electrode; M – Multimeter; E – Electrometer; R – variable resistance; C – Platinum foil.¹⁷

The two arms of the U-shaped glass cell were separated by a platinum foil barrier.

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Two platinum electrodes were placed symmetrically on two sides of the barrier. Saturated iodine/iodide solution was poured into one arm of the cell and the mixed solution of two dyes and triturated ZnO at specific potency were poured in the other arm. The variation of generated voltages and currents were measured by means of a Keithley digital multimeter (DM196). A 60 W lamp was used for illumination and the light intensity was measured with a Luxmeter (D & L Instrument MS6610). Maximum efficiency was observed for triturated ZnO at 30C potency.

Result and discussion

The photovoltage generation in EC cell has been observed using Azure C and Rose bengal solution and triturated zinc oxide (Figure-II).

Figure-II: Growth and decay curve of V_{oc} (photovoltage) generation for mixed Azure C, Rose bengal and triturated zinc oxide of potency 6C, 30C and 200C.

Figure-III: Current versus voltage characteristic curves for mixed Azure C, Rose bengal and triturated zinc oxide of potency 6C, 30C and 200C.

The I-V characteristic of the cell was studied (Figure-III) and the energy conversion efficiency has been calculated for all four cases (Table 1).

Sample used	Peak value of photovoltage (mV)	Short circuit current (µA)	One Cycle duration (minutes)	Fill factor (FF)	Energy conversion efficiency (η %)
Only mixed dye	95	5	310	0.38	0.15
Mixed dye+ZnO 6C	150	6	248	0.52	0.39
Mixed dye+ZnO 30C	134	9.5	375	0.40	0.43
Mixed dye+ZnO 200C	152	6	255	0.50	0.35

Table-I: The characteristics of an electrochemical cell using mixed Azure C, Rose bengal and triturated zinc oxide of potency 6C, 30C and 200C.

In all cases, photo-induced voltage generation upon illumination started rising with time and reached a maximum saturation value and remained constant at that value. When the light was cut off the voltage decreased slowly and the storage duration for 30C was more than 4 hrs to reach the initial value. Also at this potency,

higher efficiency of PEC cell was obtained. The photovoltage cycle was reproducible upon further illumination. The energy conversion efficiency ($\eta\%$) of the cell and the fill factor (FF) have been calculated using the following equations:

$$FF = (V_{pp} \times I_{pp}) / (V_{oc} \times I_{sc})$$

$$\eta\% = FF \times (V_{oc} \times I_{sc} \times 100) / P_{in}$$

where V_{pp} = voltage power point, I_{pp} = current power point, V_{oc} = open circuit voltage and I_{sc} = short circuit current, P_{in} = measured input power ~ 130 mW. The values of V_{oc} , I_{sc} , storage time, $\eta\%$ are summarised in Table 1.

In order to understand how trituated ZnO tuned the photoelectric properties of the dye molecules, the absorption spectra of the mixed dye in presence of trituated zinc oxide at different potencies had been studied (Figure-IV). Azure C and Rose bengal have their characteristic bands at 545 nm and 610 nm respectively. With the addition of the trituated ZnO, the characteristic peaks of the dye remain unchanged but absorbance increased.

Figure-IV: Absorption spectra of mixed Azure C, Rose bengal and trituated zinc oxide system with a concentration of mixed dyes solution $0.85\mu\text{M}$ and trituated zinc oxide of potency 6C, 30C and 200C.

Our experimental results on photovoltage generation using trituated ZnO show presence of nanoparticles of almost spherical shape and particle sizes within 5-7 nm.¹⁶ Due to adsorption of dye molecule on the surface of trituated ZnO nanoparticles, the absorption efficiency of the dye molecule increased.¹⁷ There is also a high possibility of forming exciplex between these two dyes at excited state which could not participate in the process of conversion of solar energy. The addition of trituated zinc oxide also plays a vital role here. As the dyes got adsorbed on the surface of these nanoparticles they could participate now actively in the conversion process and the problem of spectral loss was reduced by better exploitation of the incident photon. The increase in efficiency of trituated zinc oxide at 30C to 6C can be explained by the fact that with increasing potency the particle size decreases, leading to increased surface to volume ratio.¹⁸ However, at 200C the concentration of nanoparticle is very low to participate in conversion process resulting in lower efficiency than 6C and 30C.

Conclusion

Our study of photovoltage generation in a dye-sensitized photo-electrochemical cell using Azure C, Rose bengal and trituated zinc oxide at three different potencies shows that with addition of trituated zinc oxide in mixed solution of Azure C and Rose bengal system, magnitude of photovoltage, storage duration and energy conversion

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efficiency get enhanced significantly and has maximum value at 30°C potency.

Spectral studies reveal that with the addition of the nanoparticle, the characteristics of the dye solution remains unchanged while the only overall optical density of the system increases indicating that there is no chemical reaction between the dyes and the triturated zinc oxide nanoparticle.

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Conflict of Interest: None declared.

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