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Photo current enhancement of natural dye sensitized solar cell by optimizing dye extraction and its loading period

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ABSTRACT

Energy conversion performance of natural dye sensitized solar cells (DSSC) mostly relies on sensitizer. The characteristics of sensitizer are governed by its extraction process parameters. So, this investigation attempts to describe the successful conversion of visible light into electrical energy by employing turmeric (*Curcuma longa* L.) as a sensitizer that is locally available at Dhaka, Bangladesh, through using dye source in different forms and optimizing some parameters such as dye extracting solvents, pH of solvent, dye loading period and dye adsorption% onto the TiO_2 film. Sensitizers were retrieved from raw and dry turmeric by employing various solvents. The optical absorption, functional anchoring group, surface morphology and elementary composition of the annealed pure nano-crystalline TiO_2 film and dye adsorbed TiO_2 film were investigated by using UV–vis spectroscopy, FTIR, SEM and EDS analysis. Effects of different dye extracting solvents on the optical energy gap were also recorded. Different photovoltaic parameters such as short circuit current density (J_{SC}), open circuit voltage (V_{OC}), fill factor (FF) and efficiency (η%) were assessed under 100 mW/cm^2 illumination. Dependency of cell efficiency on dye loading periods and dye adsorption% onto photo electrode were also analyzed.

1. Introduction

Structural and material properties optimization for proliferating energy conversion efficiency of photovoltaic devices has been extensively uniting by photovoltaic research community. In this regards, DSSCs have conquered considerable attention for promising photon to electron conversion capability and economic viability [1].

Typically, DSSCs comprises of four components namely a photo electrode with a thin layer of wide band-gap semiconductor attached to a conducting substrate, sensitizer, electrolyte and counter electrode [1,2]. Dye harvests photon from sunlight and being excited and thus inject the energized electrons to the conduction band of the semiconductor, where electrons pass

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through the external circuit to the counter electrode. Then redox couple of electrolyte regenerates dye molecules. Electrolyte recollects its lost electron from counter electrode, thereby completes the cycle of conversion of light into electricity [2–4].

Intense absorption in visible range, profound electron turnover from incident photon, prolong excited lifetime of the electron, faster adsorption onto semiconductor surface and electron transfer via firmer grafting of dye molecules with semiconductor oxide with favorable anchorage, rapid regeneration by electrolyte, narrower gap between highest occupied molecular orbital (HOMO) and lowest unoccupied molecular orbital (LUMO), attenuated optical energy gap, lower absorption co-efficient etc. are habitually presumed as key qualities of an ideal sensitizer for DSSCs [1,5–8]. Exceptionally, ruthenium polypyridyl complexes have all of these characteristics and thus have attained significant attention for their great favorable performance amongst thousands of dyes over the past two decades [5–8]. Conversely, costly Ru metals are retrieved from long term rare natural resources. Moreover, Ru metals are heavy and resemble to pronounce environmental impediment, complex manufacturing process, uneconomical, etc. [9]. Hence, the deployments of natural dye as photosensitizer of DSSC are exorbitantly emphasized by researchers around the globe for their eco-friendly aspect, high extinction co-efficient, economic and ease of availability, abundance in supply, non-toxicity, and can be applied without further purification [8,10].

Intend to depose the practices of Ru metals, various plant pigments such as betalains, carotenoids, chlorophyll, flavonoids, etc. have been extensively explored by DSSCs research groups over the last two decades [8,10]. Turmeric is one of the amply available natural dyes which is consist of favorable functional groups and has the ability of anchoring with TiO_2 semiconductor. This yellow-orange dye i.e., 1, 7-bis-(4-hydroxy-3-methoxyphenyl)-1, 6-heptadiene-3, 5-dione, found in turmeric root has been accessed through optimizing several working parameters of DSSC [1,11–20]. Curcumin can be extracted from raw or dry turmeric by using several polar protic and aprotic solvents [6]. Each solvent possess different polarity and viscosity. The pH, polarity and viscosity of the solvent greatly govern the absorption & absorbance of the curcumin as well as its adsorption onto semiconductor layer surface [6,21–27]. Additionally, the optical energy gap is also engaged with absorption of the dye molecule [7]. So, selection of the proper dye extracting solvent is rush. Likewise, TiO_2 film impregnation period into dye solution controls the dye uptake percentage onto photo electrode semiconductor oxide surface [28–31]. Till to attaining equilibrium state, dye adsorption percentage increases with increasing loading period. But, more amount of adsorbed dye impedes electron conduction from TiO_2 surface to electrolyte and mitigates the overall photovoltaic response. Therefore, fixation of optimum loading period and adsorption% of dye are also important.

So, this study essentially indicates the optimization of curcumonoids extraction from raw and dry turmeric root by employing several polar protic and aprotic solvents, pH of solvent, dye loading period and dye adsorption% in terms of photovoltaic response.

2. Experimental

2.1. Materials

Citric acid ($C_6H_8O_7$), Acetic acid (CH_3COOH), Sodium hydroxide (NaOH), TiO_2 (Degussa P25), Triton X 100 ($C_8H_{17}C_6H_4(OCH_2CH_2)nOH$), Polyethylene glycol (PEG), Titanium IV Isopropoxide, Acetone (C_3H_6O), Ethanol (C_2H_6O), Methanol (CH_4O), Potassium iodide (KI), Iodine (I_2) were procured from Merck, Germany. Indium doped tin oxide (ITO) glass and meso porous TiO_2 (Degussa P25) were collected from Dyesol, Australia. All chemicals were analytical grade and used without any further purification.

2.2. Methods

2.2.1. TiO_2 film fabrication

According to our previous work [32] requisite amount of Degussa P25, citric acid, PEG, and Triton X-100 and Titanium IV Isopropoxide were mixed homogeneously to prepare TiO_2 slurry. Prepared slurry was deposited onto the ITO glass surface by doctoral blade technique employing glass rod and the prepared film was annealed at 450 °C in a muffle furnace. Thicknesses of the deposited films were ranging from 12 to 15 μm.

2.2.2. Dye extraction

Firstly, turmeric was washed carefully and peeled off. Raw and dry turmeric were employed separately as sensitizer source. Peeled turmeric was crushed using mortar pestle using various solvent such as acetone, ethanol and methanol separately. Then extract was filtrated and used as raw sensitizer source. For preparing dry sensitizer, turmeric was finely sliced and kept for complete drying in absence of sun light. This dried turmeric was then weighted and immersed in the same types of solvents that were used for raw turmeric separately to investigate the effect of solvent for dye extraction. Ratio between turmeric to solvent was 1 g:10 mL. After 1.5 h, these solvents extracts were filtered and collected for application. Dried turmeric dissolved in methanol exhibited the best output amongst all solvents. So this entity was considered for noticing the impact of solvent pH variation. Effect of pH (3.5, 4, 5.3, 6.7, 10.6 and 11.6) on dye extraction was investigated by adjusting the pH using requisite amount of acetic acid and NaOH respectively.