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Retrospection of Innate Dyes as Chromophores in Dye-Sensitized Solar Cells

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Abstract

In the present course of study, deliberate investigation of natural dyes versus synthetic dyes in dye-sensitized solar cells (DSSCs) has been undergone through. Although quoted efficiency values of artificial dyes like N7 dye, black dye and N719 dye etc. is efficiently higher than natural ones such as turmeric, rosella, sweet potato leaf and blue pea etc. Yet the latter meet the fundamental aim of DSSC i.e. low cost to performance ratio. Also considered dyes cause no environment threat, easily extractable, abundant and safe. Several methods to improve the performance of these innate dyes have been explored. Parameters viz. pH level of extract, extraction method, extracting temperature, multilayer configurations and usage with nanostructures can be considered as a great step to reach the higher value of output. Among natural dyes root of maharanga bi color herb, mangosteen pericarp etc. have proved their candidature as best anchoring choromophores in dye-sensitized solar cells.

Keywords: Natural dyes; Mangosteen pericarp; Maharanga bi color herb

Introduction

Due to peak demand of environmental benign energy, dye-sensitized solar cells have attracted a great deal of attention of researchers. In 1873, Herman Vogel [1] quoted that a few organic dyes could cause an enhancement in the green and red response of photographic films made of silver halide. The mechanism involved the transfer of electron or energy from the chromophore to the silver halide grain which is semiconducting. This spectral sensitization formed the basis for photography. Photovoltaic cells have also been known for a longer time. The initial was designed by E. Becquerel [2] in 1839 by using copper oxide or silver halide coated metal electrodes dipped in an electrolyte solution. On the other hand, modern solar cells are a more recent development in the first developed by D. Chapin, G. Pearson and Paul Rappaport at Bell Labs [3]. These cells consisted of a p-n junction which marks the barrier between electron and hole majority regions. Electrons and holes created through the absorption of light in silicon diffuse at in the n-doped and p-doped materials and are eventually combine at the junction. This p-n junction is formed by a process which resembles that used by the semiconductor industry to manufacture integrated circuits and computer chips. Potentially more cost effective technologies, which use thin films of such materials as amorphous silicon deposited on glass, are under development [4].

This process is very costly, so researchers explored alternative low cost sensitization processes in solar cells. Preliminary work was done by Meier et al. [5]. Then in 1991, a Swiss research group combined several concepts to produce a low cost solar cell having efficiency 7% [6,7]. The cell, which is called a dye- sensitized solar cell (DSSC), is remarkable in that it resembles natural photosynthesis as it uses an organic dye to absorb light and harness solar energy. It is one of a new class of devices which are called molecular electronic devices [8]. To fabricate the cell, a solution of particles of TiO_2 was deposited directly on conductive glass by a process similar to that used in painting. The film was heated to form a porous TiO_2 morphology which resembles a thin sponge. This was used as a photo anode and was dipped into a solution of a dye [9].

A layer of the dye molecules can be adsorbed onto the layer of TiO_2 via the carboxylic groups and acts as the fundamental absorber of sunlight. To synthesize the final cell, a drop of liquid electrolyte containing iodide is placed on the film to permeate into the pores of the semiconductor. A counter electrode of a thin layer of platinum or carbon deposited on conducting glass is placed on top. Then this sandwich type structure is ready to be illuminated by sunlight through the TiO_2 support. Since the dye layer is thin, the excited electrons produced from light absorption in the dye can be transported into the TiO_2. In contrast to conventional Si or Ga As solar cells, charge carrier transport in the light absorbing compound is not relevant to the cell design; therefore it becomes quite easier to tailor its properties to enhance the output of the cell.

In the present paper, role of natural dyes is discussed with regards to optimum cost versus performance. Although natural dyes lag behind synthetic dyes in the race of efficiency by being employed as choromophores in DSSCs, yet these open the gates to a vast research field.

Natural Dyes

A dye should possess a phenolic group that is responsible for its anchoring to the semiconducting surface. Among natural dyes anthocyanins forms a group of naturally occurring phenolic compound creditworthy for the color of many flowers, fruits and vegetables. The most vernacular anthocynidins (anthocynanins without glycoside group) found in flowers are pelargonidin (orange), cyanidin (orange-red), peoridin (orange-red), deliphinidin (blue-red), petonidin (blue-red) and melvidin (blue-red) etc. Following paragraphs will unveil the performance of few natural dyes in dye-sensitized solar cells.

Mango stein Pericarp

C. I. F. Attanayake et al. [10] have declared dye extract of mangostein pericarp as best dye out of 100 natural dyes and its performance parameters are J_{sc}=2.56 mA/cm^2, V_{oc}=685.3 mV, FF= 60.02%, η=1.053%. These parameters quantify comparable to the output of DSSC assembled by using anatase TiO_2 with N719 dye. Experimented with 20 natural dyes as sensitizers and quoted highest efficiency of mangostein pericarp [11]. Its output is J_{sc}=2.69 mA/cm^2, Voc=686 mV, FF= 63.3%, η=1.17s%. They compared different xanthone components of same dye (Mangostein pericarp) and found that Rutin was most effectual.

Lawsonia Inermis (Henna)

In Henna, color causing agent is laws one, (2-hydroxy-1, 4-naphthoquinone) also known as hennotannic acid, $C_{10}H_6O_3$, a burgundy organic compound that shows an affinity for bonding with protein as quoted its performance parameters J_{sc}=0.9 mA/cm^2, Voc=1.3V, FF= 93%, η=1.1% [12]. The solar cells synthesized using TiO2 photo anode sensitized using dye extract with pH values low, high and higher show efficiency values of 1.04%, 1.21%, 1.06 % respectively. This data clearly indicates that by optimizing pH value efficiency can be controlled and a suitable value of acidity leads to an increment in the efficiency of a DSSC. Lawson Inermis can also be experimented to get high output by changing extracting temperature as reported by Sakhtivel et al [12]. According to Sakhtivel Henna showed highest efficiency in DSSC at a temperature 75OC out of three working temperatures viz. 50OC, 75OC and 100OC. We can say that solvent, pH and extraction temperature are the keys to open the locks of high output, if explored in a right direction.

Fire fern

Oxalis hedysaroides is popularly known as fire fern; a flowering perennial plant. Its leaves are green in color but turn deep purple red due to exposure to sun. Oxalis hedysaroides is a very mobile plant and rotates its foliage significantly to follow the sun. Ivan et al. has observed that it shows absorption in a wide range 200-600 nm. If fire fern is used in acidic medium (HCl), its absorption range remains same but intensity of peaks increases appreciably. Experimented with co- sensitization of fire fern with dye obtained from begonia black velvet onto layer of TiO_2 photo anode. Combination of these dyes give better results as both are anthocyanins. Co-sensitized cell showed conversion efficiency η=1.2% and J_{sc}=5.08 mA/cm^2, Voc=4.129V, FF= 57.2% while individual devices made from fire fern (η=0.96%) and begonia black velvet (η=0.87%) are quite lesser efficient [13].

Turmeric

Turmeric is a rhizomatous herbaceous perennial plant of ginger family. It shows absorption in 200-500nm but when used with HCl, range remains same and intensity increases. Voc=600 mV [14] have observed the effect of pH on photosensitization of Curcuma longa L. (turmeric) by using HCl, HNO_3 and CH_3COOH in DSSC. They unveiled, although stronger acid increases the absorption intensity of turmeric yet it may etch the semiconductor surface and thereby decreasing output. In their experiments acetic acid was effectual to improve performance. This concludes that the acidic medium is favourable for an efficient DSSC with turmeric as dye.

Beetroot

Beta Vulgaris (beetroot) contains betalain dye that covers whole of the visible spectrum in its absorption range but highest intensity is observed in green band. Bhanushali and co-workers studied the performance of dye-sensitized solar cells using beta vulgaris (beet root) at different value of pH, temperatures and solvents [15]. Comparison of pH values showed that the more acidic the medium is the more is efficiency. It was found that 50OC temperature was best suited for their task. Bhanushali declared ethanol as the best solvent to be used with beetroot. His group reported 0.69% efficiency of DSSC in their working conditions.

Conclusion

Various dyes have been explored as sensitizers in dye-sensitized solar cells. If natural dyes are used in dye-sensitized solar cells then we can assert that we are getting a clean, cost effective and environment friendly energy. There exist a lot of dyes performing hopefully in DSSC viz. mangostein pericarp, turmeric, beet root, fire fern, maharanga bi color herb, rose Bengal etc. We have found highest output in case of rose Bengal dye used by They calculated an efficiency value of 2.09% [16]. Our group's previous studies have shown that efficiency of TiO_2 as photo anode has been significantly raised by modifying its morphology and keeping the dye same [17]. It is possible

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that same hierarchy may lead to an enhanced performance of DSSC with natural dyes and then we will be able to meet the fundamental aim of DSSC technology that is an optimized cost to performance ratio.

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