International Journal of Thin Films Science and Technology

http://dx.doi.org/10.18576/ijtfst/060208

Comparative Study on the Energy Conversion Efficiency of Dye Sensitized Solar Cell Using Different Natural Dyes

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Received: 3 Mar. 2017, Revised: 11 Apr. 2017, Accepted: 13 Apr. 2017.
Published online: 1 May 2017.

Abstract: The Dye sensitized solar cells (DSSCs) were fabricated using natural dyes extracted from different natural dyes such as Turmeric, Carissa Carandas and Beet absorbed into a nano porous TiO_2 substrate. The DSSCs provide a technically and economically credible alternate concept to present day p-n junction photovoltaic device. In contrast to the conventional silicon systems, where the semiconductor assumes both the task of light absorption and charge carrier transport the two functions are separate here. Light is absorbed by a sensitizer, which is anchored to the surface of a wide band gap oxide semiconductor charge separation takes place at the interface via photo-induced electron injection from the dye into the conduction band of solid. Carriers are transported in the conduction band of the semiconductor to the charge collector. The use of sensitizer having a broad absorption band in conjunction with oxide films of nano crystalline morphology permits to harvest a large fraction of sunlight.

The purpose of this experiment was to create high performance DSSCs using Titanium dioxide and different natural dyes as the electron donating species. Graphite coated glass was used as the counter electrode. An I^-/I^-_3 electrolyte solution was used as the redox couple The best light-to-electricity conversion efficiency was obtained when citric acid of concentration 0.1M, thickness of electrode 50 μm, dye sensitization time 30 min, annealing temperature 450^0 C, and tip of candle flame was used as a catalyst on turmeric dye in crude from extract by methanol. For Turmeric best sample showed maximum cell voltage 0.610 V, current density 0.487 mA/cm^2, fill factor 0.36% and cell efficiency 0.11%. For Carissa carandas best sample showed maximum cell voltage 0.510 V, current density 0.310 mA/cm^2, fill factor 0.66% and cell efficiency 0.10%. For Beet best sample showed maximum cell voltage 0.505 V, current density 0.306 mA/cm^2, fill factor 0.65% and cell efficiency 0.10%.

Keywords: Dye sensitized solar cell, Natural dyes, Energy conversion, and Natural sensitizers.

1 Introduction

Dye sensitized solar cell (DSSC) is a device for the conversion of visible light into electricity, based on the sensitization of wide band gap semiconductors [1].The performance of the cell mainly depends on a dye used as sensitizer. The absorption spectrum of the dye and the anchorage of the dye to the surface of TiO_2 are important parameters determining the efficiency of the cell [2]. In case of lowering the cost of production, dye-sensitized solar cells (DSSCs) based on oxide semiconductors and organic dyes or metallorganic-complex dyes have recently emerged as promising approach to efficient solar energy conversion. The DSSCs are a photo electrochemical system, which incorporate a porous-structure oxide film with adsorbed dye molecules as the photosensitized anode. A typical DSSC system composed of a mesoporous titanium dioxide film on a transparent conductor. Dye molecules are absorbed on the entire porous TiO_2 that is perused with an electrolyte containing iodide and tri iodide. A layer of additional electrolyte separates the porous TiO_2 from a counter electrode. When a photon is absorbed by a dye, the excited dye transfers an electron to the TiO_2 (termed injection) then oxidized dye can be reduced by iodide (regeneration) or can recapture an electron from the TiO_2.The electron in the TiO_2 can diffuse to a collection electrode (transport) or can be captured by a tri-iodide molecule in the electrolyte. Electrons that reach the collection electrode flow through the external circuit and reduce tri-iodide to iodide at the counter electrode [3].

The ability of doing work is energy. There are several forms of energy [4]. The forms of energy are often named after a related force. German physicist Hermann Von Helmholtz established that all forms of energy are

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equivalent energy in one form can disappear but the same amount of energy will appear in another form [5]. Fusion power could solve many of the problems of fission power but despite research having started in the 1950s, no commercial fusion reactor is expected before 2050 [6].Pump storage reservoir aren't really a means of generating electrical power. There are way of storing energy so that we can release it quickly when we need it. Dinorwing has the fastest "response time" of any pumped storage plant in the world. it can provide 1320 Mega watts in 12 seconds [7]. Most of the Earth's energy comes from the Sun. Solar power, that's obvious, but the energy in coal originally came from the Sun too. The sun provides approximately 100,000 terawatts to the earth which is about 10,000 times more than the present rate of the world's present energy consumption [8].

In the Phoenix, Arizona area, for example, the average annual solar radiation is 5.7 KWh/m2/day [9] or 2080.5KWh/m2/year. Electricity demand in the continental U.S is $3.7x10^{12}$ KWh per year. Photovoltaic cells are being increasingly used to tap into the huge resource and will play key role in future sustainable energy systems. A photovoltaic cell designed to convert sunlight into electrical energy is known as solar cell [10].solar cells do not use chemical reactions to produce electrical power, and they have no moving parts. Solar cells are safe and have few non desirable environmental impacts. Solar cells can be easily incorporated into distributive systems. Solar cells provide electricity exactly when we need it most [11] .Daguerre created the daguerreotype, the very first type of photographic image, exploiting the light-sensitivity of silver iodide [12]. The photographic field was subject to comprehensive empirical research. William Henry Fox Talbot accidentally revolutionized photography when he employed silver halide crystals on a piece of film, which reduced the exposure time from one hour(the daguerreotype) to one to three minutes, Talbot named his improved photographic process collotype [13].

This ignited discoveries in sensitization. The semiconducting silver halides used by Talbot and others at that time had band gaps of 2.7 to 3.2 eV. therefore, they did not respond to wavelengths longer than 460 nanometers, since these wavelengths are not sufficiently rich in energy to admit energy transfer across the band gap. In 1873, Hermann Vogel, a professor of photochemistry, spectroscopy and photography, discovered a way to extend the photo response of the silver halide, using certain organic dyes, so that it became sensitive to wavelengths exceeding 460 nm. From having been sensitive only to while blue light, photographs could now be sensitive to green light as well. The manufacturing of orthochromatic plates was born(the orthochromatic plates were sensitive to all the visible spectrum except red and deep orange).

Some 25 years later, in the early 20^{th} century, production of panchromatic films, sensitive to the entire visible spectrum commenced [14],[15].The first theoretical analysis of the photographic process was carried out in 1938 by Gurney and Mott[15]. Since the same photochemistry rules photography and photo electrochemical cells, the same dyes for sensitization can successfully be applied within the two fields. This was recognized by Hishiki and Namba at the International Conference on Photo sensitization of solids in Chicago in 1964[16].The postwar foundation of modern photo-electrochemistry is attributed to Gerischer[17], Brattain and Garret [15].The rise of amorphous silicon in the 1980s brought solar cells to common electronic consumer goods, pocket calculators, watches and more [18]. In 1989 a 37% efficiency was reported, when lenses to concentrate the sunlight had been employed [9].

Greatzel and O'Regan made a major contribution to the evolution of PEC cells in 1991, when they created the Greatzel cell, a nanoporous TiO_2 PEC solar cell sensitized with a ruthenium complex dye and with acetonitrile or ethylene carbonate as organic solvents for the electrolytes [19]. The large surface area of the porous nanocrystalline TiO_2 layer and the ruthenium complex dye interact to harvest a large percentage of the incident photons, high conversion efficiencies are achieved in both simulated solar light and diffuse daylight. Many groups have published papers claiming possibility of high efficiencies after conducting optical measurements under many hypothetical conditions. The efficiency should be measured under real conditions and the basic parameters that need to be evaluated are the short circuit current, open circuit voltage. [20].

A low cost photovoltaic cell is a thin film cell intended to produce electrical energy at a price competitive with traditional energy sources. This includes second and third generation photovoltaic cells, that is cheaper than first generation (crystal silicon cells,also called wafer or bulk cells). Grid parity, the point at which photovoltaic electricity is equal to or cheaper than grid power,can be reached using low cost solar cells. It is achieved first in areas with abundant sun and high costs for electricity such as in California and Japan [21].Grid parity has been reached in Hawaii and other islands that otherwise use diesel fuel to produce electricity.

George W. Bush had set 2015 as the date for parity in the USA [22][23]. Speaking at a conference in 2007, General Electric's Chief Engineer predicted grid parity without subsidies in sunny parts of the United States by around 2015 [24]. One research firm predicted that new manufacturing capacity began coming on line in 2008(projected to double by 2009) which was expected to lower prices by 70% in 2015.Other analysis warned that capacity may be slowed by economic issues, but that demand may fall because of lessening subsidies.Other potential bottlenecks which have been suggested are the capacity of ingot shaping and wafer slicing industries, and

the supply of specialist chemicals used to coat the cells [25].

Low cost is a very important benefit of producing dye sensitized solar cells compared to the widely used conventional silicon solar cell. Moreover, enhanced dye sensitized solar cell efficiency would provide enormous economical advantages. Recently, nano sized TiO_2 powder have been used as a working electrode for dye sensitized solar cells(DSSC) due to a higher efficiency than any other metal-oxide semiconductor. However, as reported, the best TiO_2 solar cell efficiency could hardly reach 10%.Therefore, photo-generated charge recombination should be prevented for enhanced efficiency because solely enlarging the oxide electrode surface area is not sufficient. A very thin metal oxide layer has often been applied, forming a passive layer and preventing injected dye electron recombination between TiO_2 and electrolytes. However in this study, doping elements were designed to substitute the lattice Ti element, not to form a passive layer. Rather, fabricating a cell using combined surface area and charge transfer enhancement by doping would be a more promising solution. We investigate nano sized TiO_2 doping to enhance photovoltaic efficiency.

2 Experimental

2.1 Materials

The materials used in this experiment were Indium Tin Oxide (ITO) coated glass plate (Dyesol, Australia),TiO_2, Citric Acid($C_6H_8O_7$), PEG, Triton X-100(Merck, Germany), Methanol (Germany), Ethanol (Germany) and Acetone(Germany), Dye extracted from Turmeric, Carissa Carandas and Beet(Local Bangladeshi name Kacha holud, Karamcha and Beet) dye in our lab, Carbon, Potassium Iodide and Iodine.

2.2 Dye Extraction

Dye was extracted from Turmeric (Local Bangladeshi name Kacha holud), Carissa Carandas and Beet collected from local market. The dye was extracted using methanol solvent. The leaves were mashed in a mortar and pastle with small amount of solvent. Then 50 ml of solvent (equivalent to the weight of leaves) was added, beaker was covered with aluminum foil & kept in a dark place for 60 minutes and then filtrated several times and collected in a dark bottle.

2.3 Electrode Preparation

The 2.54cmx2.54cm ITO glass plates used for the experiment were washed in methayel alcohol to remove any contaminants from their surface. A multi meter was used to test the resistivity of the conductive sides of each glass plate. Readings were taken between 20Ω and 30Ω. The conductive sides of the glass plates were masked 5mm from opposite edges with scotch tape to provide a 10-12 micron deep channel for the TiO_2, resulting in $1cm^2$ surface area for deposition.15µl of colloidal suspension was used for deposition of each plate to satisfy the 5 $\mu l/cm^2$ requirement, it is noted that the high content of glacial acetic acid breaks down the scotch tape. The masked glass cells were then secured as the colloidal suspension was dispensed, using a glass stirring rod to apply an even uniform coat across the cell. The cells were allowed to air dry for five minutes .the plates were then annealed in a Muffle Furnace at 450^0C for 60 minutes, and then cooled to room temperature. Then the surface morphology of the thin film was analyzed by using electronic microscope.

2.4 Soaking of Electrode

The TiO_2 coated glass plate was soaked in turmeric dye for 2 hrs in dark and sealed place. Then glass plate was washed using ethanol and dried in air for few minutes.

2.5 Electrolyte Preparation

0.83g of 0.5M potassium iodide and 0.127g of 0.05M iodine was mixed in 10ml methyleneglycol. The solution was stored in a black bottle. This solution is used as the electrolyte.

2.6 Counter Electrode Preparation

The counter electrodes were evenly coated with a thin layer of carbon on the conductive sides of the glass plates. The counter electrode was prepared by exposing the conductive side of an ITO coated glass to candle light for 2-3 minutes which leaves a dark shade of carbon on the glass.

2.7 Cell Fabrication

Electrode and counter electrode were combined together keeping TiO2 paste coated surface and the carbon coated surface face to face. 2/3 drops of electrolyte solution was given in the contact of two glasses and by the capillary action the electrolyte was uniformly distributed throughout the stained TiO2 film. Excess electrolyte from the exposed area of the glass was wiped off by using cotton or tissue. The complete cell was then taken to sunlight for illumination.

2.8 Measurements of cell Performances

When completed, the ready DSSC was energized using a light source of a 55-W Xenon lamp mounted inside a solar simulator under illumination of $500w/m^2$(calibrated using a pyrometer).The lamp almost imitates spectrum of sunlight. The current, voltage and resistance of the cell was measured by a multimeter. The cell performance was measured using AGILENT 34401A precition multimeter. The testing temperature was 25^0C-27^0C.

2.9 Effect of different Natural Dyes

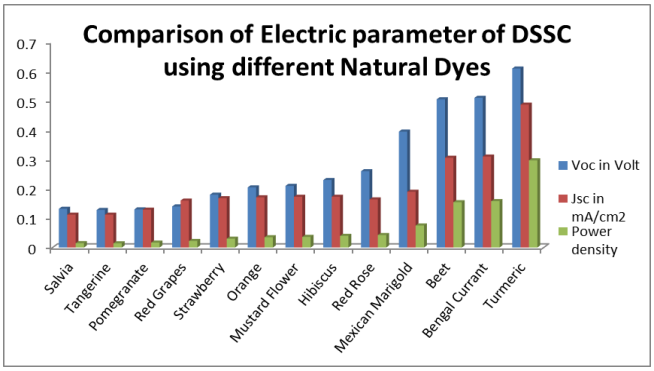

Figure 1: Comparison of different Natural Dyes

Table 1: Current Density and Power Density of different Natural Dyes

No. of Exp.	English Name	Local Name	Voc in V	Jsc in mA/cm^2	Power Density mW/cm^2
01	Salvia	Salvia	0.132	0.112	0.0148
02	Tangerine	Komola	0.128	0.112	0.0143
03	Pomegranate	Bedana	0.130	0.129	0.0168
04	Red Grapes	Lal Angur	0.140	0.160	0.0224
05	Strawberry	Strawberry	0.180	0.168	0.0302
06	Orange	Multa	0.205	0.171	0.0351
07	Mustard Flower	Sarseful	0.210	0.173	0.0363
08	Hibiscus	Jaba	0.230	0.173	0.0398
09	Red Rose	Lal Golap	0.260	0.164	0.0426
10	Mexican Marigold	Holud Gadaful	0.395	0.190	0.0750
11	Beet	Beet	0.505	0.306	0.1545
12	Bengal currant	Karamcha	0.510	0.310	0.1581
13	Turmeric	Kacha Holud	0.610	0.487	0.2971

3 Results and Discussion

In this experiment we use Titanium dioxide (TiO_2) in natural dye sensitized solar cell (DSSC). Finally we got the best performance Turmeric dye which is locally available in Bangladesh.

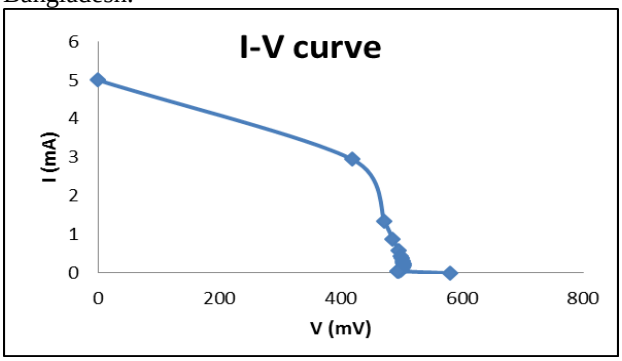

Figure 2: Current density-Voltage (I-V) Curve for turmeric dye at 450^{0}C

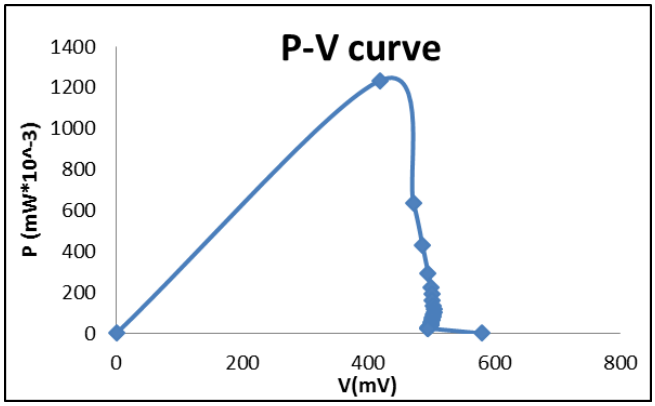

Figure 3: Power-Voltage (P-V) curves for turmeric at 450^{0}C

Table 2: Turmeric Dye with methanol solvent at 450^{0}C

No.	V(mV)	I(mA)	P = (V*I)
Isc	*0*	*5.650*	*0*
1	419	2.948	1235.21
2	472	1.343	633.896
3	486	0.886	430.596
4	495	0.594	294.030
5	499	0.446	222.554
6	501	0.384	192.384
7	502	0.321	161.142
8	503	0.263	132.289
9	504	0.233	117.432
10	504	0.206	103.824
11	503	0.179	90.037
12	503	0.161	80.983
13	502	0.147	73.794
14	502	0.136	68.272
15	501	0.126	63.126
16	500	0.113	56.500
17	500	0.103	51.500
18	499	0.087	43.413
19	499	0.079	39.421
20	498	0.072	35.856
21	497	0.068	33.796
22	496	0.060	29.760
23	495	0.057	28.215
24	494	0.052	25.740
25	494	0.050	24.700
Voc	*610*	*0*	*0*

Table 3: Input Data

Input:	
Isc(mA) =	5.65
Voc(mV)=	610
L (cm) =	6.1
W (cm)=	1.9
Area, A =	11.59
i/p Power	
Pin =	100

Table 4: Output Data

Output:		
P max	Vmax	Imax
1235.21	419	2.948
Current density:		
Jm= Im/A	0.25436	mA/cm^2
Jsc=Isc/A	0.45298	mA/cm^2
Fill Factor	: FF =	0.3556525
FF=(Vm*Jm)/(Voc*Jsc)		
Efficiency:	0.11352	
Ƞ =	(Voc*Jsc*FF*100)/Pin	

3.1 Measuring Electric Properties

Electrical properties were measured by using two digital multimeter keeping the cell in sunlight of approximately 100 mW/cm^2 illumination. Current and voltage were measured by multimeters changing with resistance with the help of a variable resistor. Based on I-V curve, the fill factor (FF) Was defined as

FF= (I_{max} × V_{max}) / (I_{sc} × V_{oc}) × 100% = (2.948×419)/(5.65×610) × 100 % = 36 % Where I_{max} and V_{max} are the photocurrent and photovoltage for maximum power point (P_{max}).I_{sc} and Voc are the short circuit photocurrent and open circuit photovoltage respectively. The overall energy conversion efficiency (η) is defined ass

η = (Voc × Jsc × FF) / P_{in} = (610 × 0.45298 × .36) / 100 = 0.9947 %

Where Pin is the power of incident light.

3.2 Ultraviolet-visible spectroscopy (UV-Vis) of Turmeric Dye

The absorption spectrum of turmeric dye was obtained using UV-Vis. The wavelength range of spectrum lays between 380nm to 510nm. The related spectrum is shown in above figure. It found that, the turmeric dye have peak absorption at 280nm and 620nm. The figure demonstrates the agent UV–Vis absorption spectra of dyes extracted from turmeric. It is found that dyes extracted by methanol of room temperature absorption peak at 620 nm compares to the energy of 0.44 eV and another higher absorption peak is 260-280 nm relates to the energy of 0.74 eV.

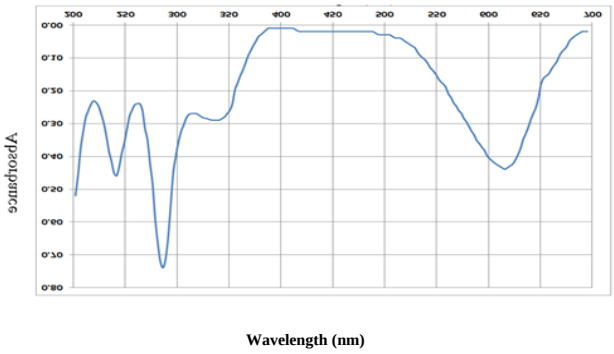

Figure 4: UV-Vis absorption spectra of turmeric dyes extracted by methanol

4 Conclusion

Bangladesh is an energy starved nation and with the rising requirement for energy the reliance on renewable energy assets have turned out to be unavoidable. In any case, customary solar cells are made utilizing semiconductor silicon materials. Because of their high creation cost contrasted with efficiency ,the utilization of semiconductor based solar cells are restricted and is not achievable for mass reception by the needy individuals of the nation. DSSC can essentially bring down the cost of assembling solar boards and cost of per unit power generation .Thus DSSC can be extremely instrumental in giving power to off framework communities and in boosting standard power generation.

Presently, the majority of the solar panels utilized as a part of Bangladesh are foreign from China and European nations. Our innovation will empower us to fabricate solar panels at focused costs and even fare solar panels. The essential elements of DSSC are copious in our condition and henceforth solar panels can be produced locally.

Acknowledgements

This work was funded by Ministry of Science and Technology, Government of Bangladesh and supported by the University Grand Commission of Bangladesh and Ministry of Education, Bangladesh. This work was carried out in Institute of Radiation and Polymer Technology (IRPT) lab of Bangladesh Atomic Energy Research Establishment (AERE) and Department of Physics of Jahangirnagar University.

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