Optical Properties of Natural Dye from Strawberry Fruits as Photosensitizer for Dye-Sensitized Solar Cells Application

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Abstract

Natural dye extracted from Strawberry fruits was used as dye sensitizer in this study. Extraction of natural dye was done using different solvents as ethanol, acetone and isopropanol. Optical properties of natural dye were studied by UV-vis spectroscopic measurement. Characterization results showed high absorbance values 0.3764, 0.2251 and 0.42 at 615 nm, 510 nm and 525 nm for ethanol, acetone and isopropanol. The optimum energy band gap values in this study were 2 eV, 2.42 eV and 2.35 eV at 615 nm, 510 nm and 525 nm for ethanol, acetone and isopropanol solvents at room temperature (25 ^{o}C). The optimum values of absorption coefficient of Strawberry dye with ethanol, acetone and isopropanol solvents were 1.76 km^{-1}, 2.12 km^{-1} and 2.06 km^{-1} at room temperature (25 ^{o}C). In this study, two methods were used to calculate the band gap energy values and they were nearly equal.

Keywords : Strawberry dye, photosensitizer, absorbance and band gap energy

Introduction

A dye-sensitized solar cell (DSSC) is a device for converting light energy into electricity. DSSC offered the advantages as new class of low cost and easy to fabricate, and can achieve high solar energy conversion efficiency [1]. Also, they are not involved in the complex technology so that they can reduce of production cost and the materials are easily obtained from the environment [2]. The standard structure of a DSSC consists of transparent conducting oxide as substrate (e.g. FTO or ITO), semiconductor layer from TiO_2 or ZnO as photo anode, Pt or C as counter electrode, dye molecules as photosensitizer, and electrolyte as electron transfer media [3]. One of the main factors which affect in the DSSC performance is dye. Dyes are classified into organic (natural dye) and inorganic dye. Inorganic dyes such as Ruthenium (Ru) dyes are presently known to be the most significant dye for the fabrication of DSSCs with great efficiency. However, they are quite expensive and difficult in their purification. Therefore, in finding alternative to the expensive and rare inorganic sensitizers, natural dyes are considered as the best viable alternative. The main advantages of using natural pigment as sensitizer in DSSCs are low fabrication cost, easy achievability, lowtime of energy payback, flexibility, and availability supply of raw materials, non-environmental risk, and great performance at diffuse light and multicolor options [4]. The dyes have been developed by the researchers, both synthetic and natural dyes. In current studies of DSSCs, synthetic dyes can reach conversion efficiency at 11% – 12% [5, 6]. Natural dyes can be extracted from various plants, fruits, flowers, and leaves [7]. Many researches have been developed kinds of natural dyes. Chang et al. employed chlorophyll dye from wormwood and anthocyanin dye from red cabbage as sensitizer in DSSC and reported conversion efficiency of 0.9% and 1.47%, respectively [8]. Among natural dye sensitized solar cells, Wang et al., (2006) have achieved 4% efficiency [9].

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Researchers have also attempted for many other natural materials as dyes, few articles which gives vast scope of field is mentioned [4, 10]. However, natural DSSCs efficiency is less compared to well established solar cells technology, which call for detailed investigation in this filed. In view of these, in the present work, dye from strawberry fruits (anthocyanin pigment) was extracted and the optical properties of natural dye solutions were studied.

Experiment

This experimental section describes the extraction and characterization of strawberry dye solutions.

Extraction of Natural Dye Solutions from Strawberry Fruits

Strawberries contain anthocyanin pigment which is in red purple color. Strawberries were purchased from Chinese Night Market (Mandalay City). Firstly, ripe strawberries were taken and washed multiple times with water to remove all the impurities and contamination to extract strawberry dye. The cleaned fruits were ground using mortar and pestle to make strawberries paste. Strawberries pastes were weighted from 5×10^4 ppm to 75×10^4 ppm and were placed in glass bottles respectively. To find the optimal concentration, 5ml of ethanol was added in it and stirred using a magnetic stirrer at 400rpm with room temperature for 30 min. Then, it was studied by UV-vis Spectroscopic measurement. From this result, the optimal concentration is obtained 33.33×10^4 ppm. Moreover, 5ml of different solvents (ethanol, acetone and isopropanol) were added in strawberries paste (33.33×10^4 ppm) and dissolved for 30 min at different temperatures (25 ^oC, 45 ^oC, 60 ^oC, 75 ^oC and 90 ^oC) at 400 rpm for 30 min. Finally, the resulting liquid was filtered out using filter paper and dye was extracted and characterized. The extraction of Strawberry dye solutions is shown in Fig. 1.

Characterization and Measurement

In this work, UV-vis spectrophotometry and band gap energy was used as characterization and measurement for Strawberry dye solution.

UV-vis spectrophotometry is a technique to measure either absorbance or transmittance of the sample in ultraviolet and visible region. The optical properties of Strawberry dye solutions were explored by UV-vis spectrophotometer (GENESYS 10S). The absorption spectra of Strawberry dye solutions were recorded in the wavelengths ranging from 300 nm to 900 nm. The reference solution was used as baseline scan before the measurement.

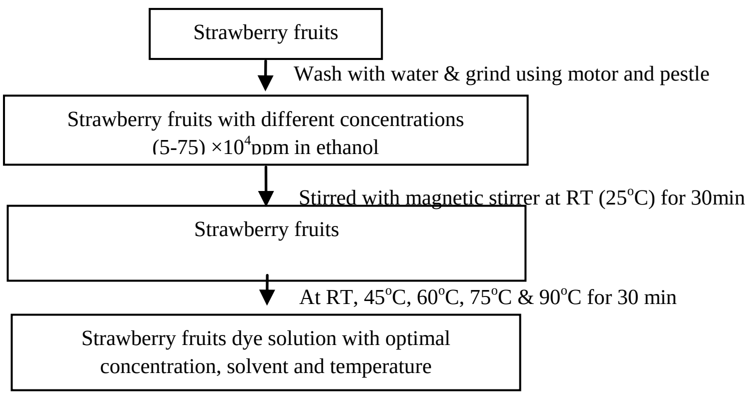

Fig. 1. Flow Chart for Synthesis of Spinach Dye Solution

Results and Discussion

Optical Absorbance of Strawberry dye Solutions

The UV-visible absorption spectra of Strawberry dye solutions synthesis with different solvents (ethanol, acetone and isopropanol) for 25 ^{o}C, 45 ^{o}C, 60 ^{o}C, 75 ^{o}C and 90 ^{o}C in the wavelength range of 300 – 900 nm were shown in Fig. 2 , Fig. 3 (a, b and c) and Fig. 4.

Fig. 2 shows the absorption spectrum of strawberry dye solutions. It was observed that there are two parts. In the first part, the absorption spectrum of the dye extract from Strawberry concentrations (5×10^4 – 25×10^4) ppm were observed between the wave length of 400 nm and 650 nm. In the second part, the absorption spectrum of the dye extract from Strawberry concentrations (33.33×10^4 – 75×10^4) ppm were observed between 575 nm and 720 nm and shifted towards longer wavelength. So, it was observed that they are red-shifted. Among them, 33.33×10^4 ppm of Strawberry concentration was optimized. The maximum peak was observed at 615 nm. The peak intensities increased with increasing dye concentrations.

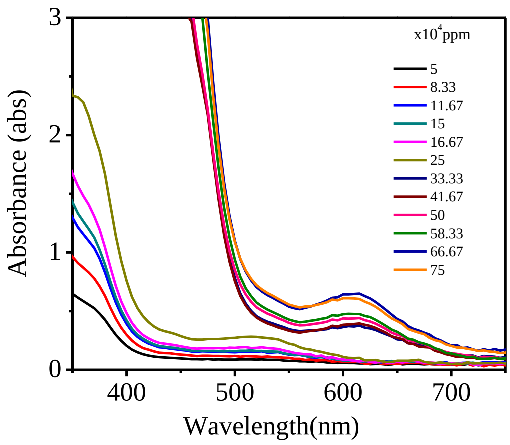

Fig. 2. Absorption Spectrum of the Different Concentrations in Ethanol for Strawberry Fruit Extracts

Fig. 3 (a) shows the result of UV-visible spectroscopic measurement of the dyes from strawberry fruit with ethanol for 25 ^{o}C, 45 ^{o}C, 60 ^{o}C, 75^{o}C and 90 ^{o}C in the range of 300 nm - 900 nm. The peak positions of natural dye solution changed for dye solution in ethanol. Then, it was observed that the optimal temperature is 25 ^{o}C. It is also red-shifted.Fig. 3 (b and c) depict the result of UV-visible spectroscopic measurement of the dyes from strawberry fruit with acetone and isopropanol for 25 ^{o}C, 45 ^{o}C, 60 ^{o}C, 75 ^{o}C and 90 ^{o}C in the range of 300 nm - 900 nm. The peak positions of natural dye solution unchanged for dye solution. Then, it was observed that the optimal temperatures are 60 ^{o}C respectively. Increased absorption intensity at respective higher temperature is due to the better solubility that would facilitate the penetration of the solvent into the dye molecular structure.

Fig. 4 exhibits the result of UV-visible spectroscopic measurement of the dyes from strawberry fruit with different solvents such as ethanol, acetone and isopropanol for 25 ^{o}C in the range of 300 nm - 900 nm. The optimal solvent is ethanol because its peak shifts towards longer wavelength. Moreover, the wavelengths of absorption edge were 560 nm and 725 nm at room temperature and the maximum peak was observed at 615 nm. It is also observed the red-shift. Ethanol is better than acetone and isopropanol for solubility of dye. It is expected that the concentration of dyes would be higher in ethanol than acetone and isopropanol, probably because of a higher solubility.

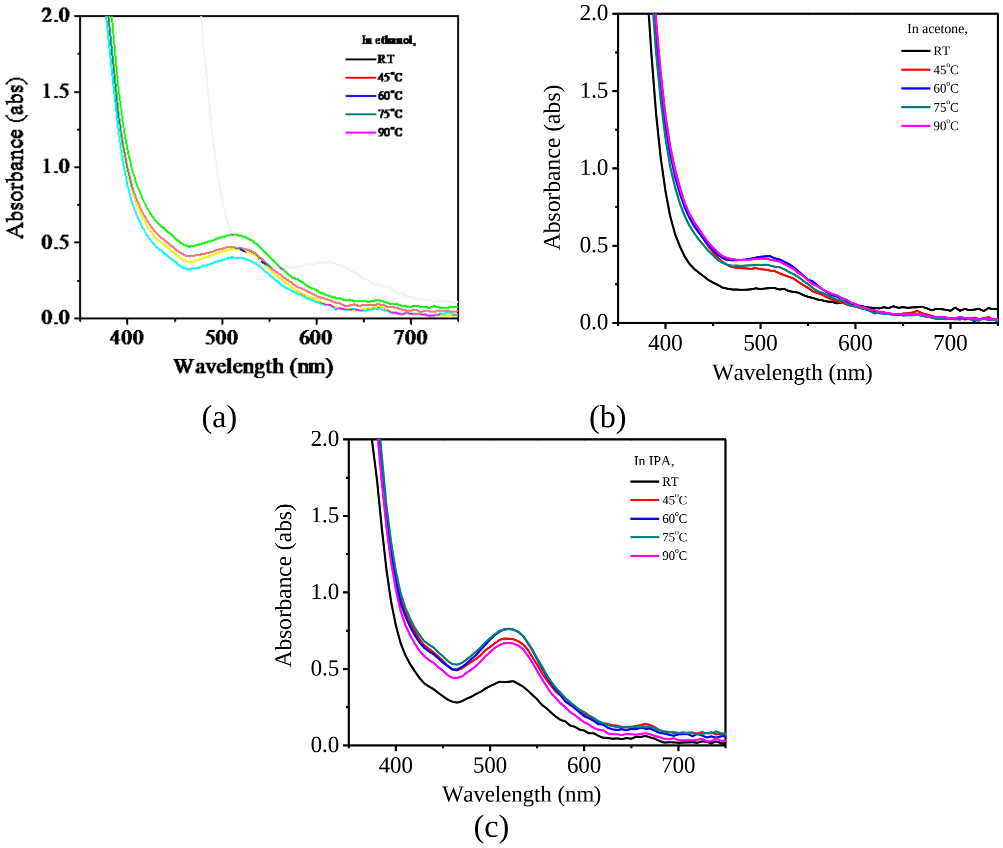

Fig. 3. Absorption Spectrum of the Different Temperatures in (A) Ethanol, (B) Acetone, (C) Isopropanol for Strawberry Fruit Extracts.

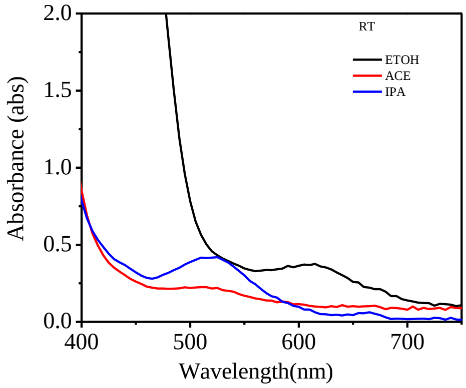

Fig. 4. Absorption spectrum of the different solvents at room temperature for Strawberry fruit extracts

Band Gap Energy Analysis (Method 1)

The value of band gap energy (Eg) of strawberry dye solutions plotted for direct transition $(\alpha h\nu)^2$ verses hν of the sample. The determination of the band gap energy of samples was used by the equation (1).

$$(\alpha h\nu) = A (h\nu - Eg)^n \qquad (1)$$

where, α = absorption coefficient

hν = the energy of photon

Eg = the direct band gap

A = the constant.

The exponent ‘n’ depends on the type of transition. For direct allowed transition n=1/2, for indirect allowed transition n=2, for direct forbidden transition n=3/2 and for indirect forbidden transition n=3. The (αhν)2vshν plot of extract strawberry dye solutions were shown in Fig. 5. In this figure, the extra plotting linear region gives the value of band gap energy (Eg) of extracted simple. Also the band gap energy (Eg) of strawberry dye solutions was listed in Table 1. The band energy value of dyes was calculated by using equation (6). From this result, it was observed that the value of band gap of dye for ethanol is 2.1 eV, 2.95 eV, 2.94eV, 2.9 eV and 2.8 eV at RT(25 ^{o}C), 45 ^{o}C, 60 ^{o}C, 75 ^{o}C and 90 ^{o}C respectively. Moreover, the band gap values of dyes for acetone and isopropanol are 2.59eV and 2.8eV for room temperature (25 ^{o}C), 2.8 eV and 2.1 eV for 45 ^{o}C, 2.81 eV and 2.14 eV for 60 ^{o}C, 2.89 eV and 2.1eV for 75 ^{o}C, 2.81 eV and 2.8 eV for 90 ^{o}C respectively. From this result, the band gap energy increases with increasing temperature except acetone solvent.

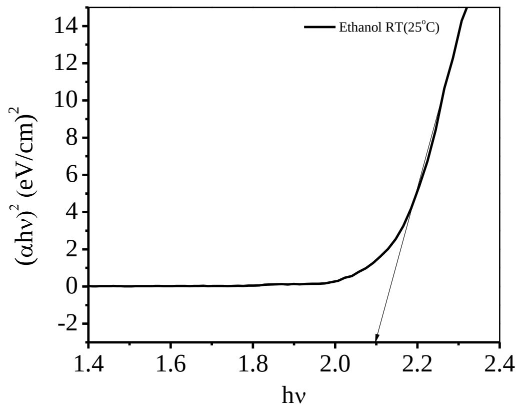

Fig. 5. Plot of $(\alpha h\nu)^2$ vs hν for Strawberry dye in ethanol at room temperature (25^{o}C).

Band Gap Energy and Absorption Coeffcient (Method 2)

The wavelength of light absorbed was tested using UV-vis Spectrophotometer which is used to determine the absorbance rate in the visible light spectrum and the intensity compositions of dye color. The band gap of dye determines by using the formula in equation (2).

$$E = h\nu = hc/\lambda \qquad (2)$$

Where h is the Planck’s constant, ν is the frequency, c is the speed, λ is the wavelength and E is photon energy .The numerical value of the symbols are: h=6.63 x 10-34 Js, c =3.0 x 108 m/s, 1 eV = 1.60 x 10-19 J.

Table 1 The Band Gap Energy of Strawberry Dye Solutions in Different Solvents at Different Temperature

Dye	Extract Solvent	Extract Temperature	Eg (eV)
Strawberry fruit	Ethanol	RT(25 ^oC)	2.10
		45 ^oC	2.95
		60 ^oC	2.94
		75 ^oC	2.90
		90 ^oC	2.80
	Acetone	RT(25 ^oC)	2.95
		45 ^oC	2.80
		60 ^oC	2.81
		75 ^oC	2.89
		90 ^oC	2.81
	Isopropanol	RT(25 ^oC)	2.10
		45 ^oC	2.10
		60 ^oC	2.14
		75 ^oC	2.10
		90 ^oC	2.80

The absorption coefficient determines how far into a material; a light of a particular wavelength can penetrate before it is absorbed. The absorption coefficient of the respective wavelengths is obtained by the division of the absorbance with the wavelength shown in equation (3).

Absorption coefficient, $\alpha=4\pi k/\lambda$ (3)

Where λ (nm) is taken from the cutoff wavelength of the dyes and k is the Boltzman constant with value of 8.617 x 10-5 eV/K.

The band energy and absorption coefficient values of Strawberry dye solutions were listed in Table 2. The band energy and absorption coefficient values of Strawberry dye solutions were calculated by using equation (2) and (3). From this result, it was observed that the value of band gap of dye for ethanol is 2 eV, 2.42 eV, 2.39 eV, 2.42 eV and 2.42 eV at RT (25 ^{o}C), 45 ^{o}C, 60^{o}C, 75 ^{o}Cand 90 ^{o}C respectively. Besides the band gap values of dyes for acetone and isopropanol are 2.42eV and 2.35eV for room temperature (25 ^{o}C), 2.49 eV and 2.39 eV for 45 ^{o}C, 2.42 eVand 2.37 eV for 60 ^{o}C, 2.44 eV and 2.37 eV for 75 ^{o}C, 2.46 eV and 2.39 eV for 90 ^{o}C respectively. From the results, it was found, the values of band gap of dyes were changed with increasing temperatures. This effect is due to the dependent of samples on temperatures. Moreover, The values of absorption coefficient of dye in ethanol were obtained 1.76 km^{-1}, 2.12 km^{-1}, 2.1 km^{-1}, 2.12 km^{-1} and 2.12 km^{-1} at different temperatures (25 ^{o}C, 45 ^{o}C, 60 ^{o}C, 75 ^{o}C, 90 ^{o}C) respectively. In acetone solvent, the absorption coefficient values were 2.12 km^{-1}, 2.18 km^{-1}, 2.12 km^{-1}, 2.14 km^{-1} and 2.16 km^{-1} at different temperatures. In isopropanol, the absorption coefficient values were 2.06 km^{-1}, 2.1 km^{-1}, 2.08 km^{-1}, 2.37 km^{-1}, 2.37 km^{-1} at different temperatures. From all this results, the high peak absorbance wavelength as red shift, low band gap and low absorption coefficient are obtained in ethanol, acetone and isopropanol at room temperature. The absorption intensity increases with increasing temperature for all extracting solvents. In this study, it was observed that the both method 1 and method 2 were nearly equal values of energy band gap of strawberry dye solutions.

Conclusion

The natural dyes were extracted from strawberry fruits as a sensitizer for dye-sensitized solar cells. The Optical properties of Strawberry extract were studied by UV-vis spectroscopy. The Band gap energy of Strawberry dye was calculated using Equation (1) and Equation (2). Optical properties of strawberry dye showed narrow band of absorbance from 400 nm to 700 nm. The values of absorption coefficient of dye in ethanol were obtained 1.76 km^{-1}, 2.12 km^{-1}, 2.1 km^{-1}, 2.12 km^{-1} and 2.12 km^{-1} at different temperatures (25 ^{o}C, 45 ^{o}C, 60 ^{o}C, 75^{o}C and 90^{o}C) respectively. In acetone solvent, the absorption coefficient values were 2.12 km^{-1}, 2.18 km^{-1}, 2.12 km^{-1}, 2.14 km^{-1} and 2.16 km^{1} at different temperatures. In isopropanol, the absorption coefficient values were 2.06 km^{-1}, 2.1 km^{-1}, 2.08 km^{-1}, 2.37 km^{-1}, 2.37 km^{-1} at different temperatures. This result showed strong absorbance in 400 nm to 700 nm wavelength and above 700 nm with little reduced absorbance. Varying the solvents and temperatures would modulate the absorption properties of dyes.Our results suggest that ethanol is better than acetone and isopropanol for solubility of dye.The high peak absorbance wavelength as red shift, low band gap and low absorption coefficient are obtained in ethanol, acetone and isopropanol at room temperature.The absorption intensity increases with increasing temperature for all extracting solvents. Therefore, strawberry optical properties proved the dye as good absorber hence it can be used for cell fabrication.

Table 2 The Peak Absorbance Wavelength, Absorption Edges Wavelength, Band Gap Energy and Absorption Coefficients of Strawberry Dye

Dye	Extract solvent	Extract temperature	Maximum peak absorbance Wavelength (nm)	Absorption edge Wavelength (nm)	Eg (eV)	Absorption Coefficient (α) (km^{-1})
Strawberry fruit	Ethanol	RT(25 ^{o}C)	615	560-710	2.00	1.76
		45 ^{o}C	510	460-625	2.42	2.12
		60 ^{o}C	515	460-600	2.39	2.10
		75 ^{o}C	510	460-625	2.42	2.12
		90 ^{o}C	510	465-630	2.42	2.12
	Acetone	RT(25 ^{o}C)	510	480-585	2.42	2.12
		45 ^{o}C	495	490-590	2.49	2.18
		60 ^{o}C	510	470-620	2.42	2.12
		75 ^{o}C	505	480-590	2.44	2.14
		90 ^{o}C	500	485-630	2.46	2.16
	Isopropanol	RT(25 ^{o}C)	525	465-630	2.35	2.06
		45 ^{o}C	515	460-635	2.39	2.10
		60 ^{o}C	520	465-625	2.37	2.08
		75 ^{o}C	520	465-625	2.37	2.08
		90 ^{o}C	520	465-640	2.37	2.08

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