Optical Properties of Dye Solutions for Dye-sensitized Solar Cell

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Abstract- The dye sensitizer plays an important role of absorption photons in the ultra-violet, visible and infrared regions of solar spectrum. So, the dye sensitizer has to be broad absorption band, non-toxicity, stability and good matching of HOMO/LUMO levels of the dye with the bottom edge of conduction band of semiconductor and the redox potential of electrolyte. It is necessary to make the good chemical bonding between the semiconductor and the dye for effective electron transfer. In this work, the optical properties of natural dyes extracted from the leaves of Henna, Teak and Burmese iron-wood have been studied by UV-VIS spectroscopy to improve the efficiency of dye-sensitized solar cell. The band-gap energies of dye solutions are about 1.8 eV. According to the light harvesting efficiencies of different natural dyes, Henna and Teak strongly absorb the high-energy photons in UV region, and they can also absorb the photons in the visible region up to 700 nm. Furthermore, Teak has the broader absorption range and can absorb the photons in NIR region. But Burmese Ironwood dye cannot absorb high energy photons in the UV and visible regions. It was found that Henna dye possesses more LHE(%) than Teak and Burmese Ironwood.

Index Terms- band-gap, DSSC, HOMO, IPCE, LHE(%), LUMO

1. INTRODUCTION

Serious environmental problem called global warming can cause due to the large amount of carbon dioxide emission by combustion of fossil fuel. And then no viable method has been found to dispose of the dangerous nuclear fuel wastes yet. So, the searching for clean and sustainable energy resources has become an urgent work for human beings.

The sun is a very abundant and democratic source of energy that can be freely and directly supplied to our home. If the small fraction of sun light could be converted to alternative and usable energy forms, there would be no worry about the energy supply line. So, solar energy is the perfect clean energy resource to solve the serious environmental problem, and the searching for affordable solar energy technology is one of the hottest research fields all over the world.

In dye-sensitized solar cell (DSSC), the absorption of high energy photons in the UV and visible region is important for the dye sensitizer. Broader absorption band is an essential fact of dye solution. And then the good adhesion must exist between the semiconductor and the dye sensitizer. And the HOMO level of dye needs to match with the redox potential of electrolyte and LUMO level is for the conduction band of semiconductor.[1-6][10,11,13]

In this work, optical properties, band-gap energy and light harvesting efficiency (LHE%) of dye solutions extracted from Henna, Teak and Burmese Ironwood leaves have been analyzed by UV-VIS spectroscopy.

In DSSC, the incident photon-to-current conversion efficiency (IPCE) is determined by LHE%.

$$IPCE = LHE\ \Phi_{inj}\ \eta_c$$

Φ_{inj} = the quantum yield of electron injection

η_c = the collection efficiency of the injected electrons at the back contact

If Φ_{inj} and η_c are close to 100%, IPCE is equal to LHE. Fig 1.1 shows the structure and operation principle of TiO_2 based DSSC.[15-17]

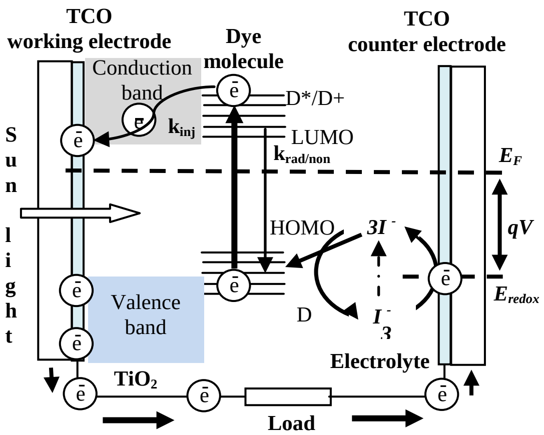

Fig 1.1 Structure and operation principle of TiO_2 based dye-sensitized solar cell

II. BACKGROUND THEORY

2.1. UV-VIS Spectroscopy

Ultraviolet visible (UV-VIS) spectroscopy is the absorption spectroscopy in the ultraviolet-visible spectral region. The absorption in the visible range directly affects the perceived color of the chemical involved. Absorption of UV-VIS radiation causes electronic transitions from the ground state to the excited state in atoms or molecules. The minimum energy required for electronic transition from the valence band to the conduction band is known as the band-gap energy. So, measuring the band-gap energies for the materials used in photovoltaic cell is important.

Beer-Lambert law states that the absorbance of a solution is directly proportional to the concentration of the absorbing species in the solution and the path length.

$$A = \varepsilon\ c\ L = \log_{10} \frac{I_0}{I}$$

A = absorbance
ε = molar absorptivity or extinction coefficient
c = concentration of the absorbing species
L = path-length
I_0 = intensity of light before passing through the sample I = intensity of light after passing through the sample

$$\%T = \frac{I}{I_0} x100\%$$

T = transmittance
I_0 = intensity of light before passing through the sample
I = intensity of light after passing through the sample

The reflectance (R) of the sample can be evaluated by the relation.

$$R + T + A = 1$$

R = reflectance
T = transmittance
A = absorbance

The light harvesting efficiency (LHE%) of dye solutions can be calculated from the absorbance data by using the formula.[14]

$$\%LHE = (1 - 10^{-A})x100\%$$

LHE = light harvesting efficiency
A = absorbance

The absorption edge is the point on the absorption spectrum with minimum energy required for electronic transition. The wavelength at the absorption edge can be used to calculate the energy band-gap of the solution. Fig 2.1 shows visible spectrum of electromagnetic radiation.

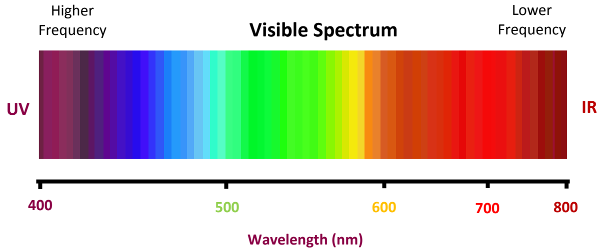

Fig 2.1 Visible spectrum

When white light passes through or is reflected by a colored substance, some photons with certain wavelengths are absorbed. The remaining light will appear as the perceived color as shown in Fig 2.2. Table 2.1 is the relationship between absorbed color and perceived color. UV-VIS spectrophotometer is shown in Fig 2.3.[7-9][12]

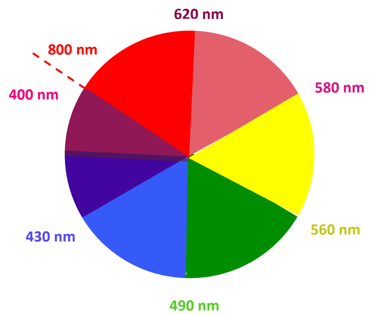

Fig 2.2 Color wheel

Table 2.1 Relationship between absorbed and perceived colors

Absorbed wavelength	Absorbed color	Perceived color
380-420 nm	Violet	Yellow-green
420-440 nm	Violet-blue	Yellow
440-470 nm	Blue	Orange
470-500 nm	Blue-green	Red
500-520 nm	Green	Purple
520-550 nm	Yellow-green	Violet
550-580 nm	Yellow	Violet-blue
580-620 nm	Orange	Blue
620-680 nm	Red	Blue-green
680-780 nm	Purple	Green

Fig 2.3 Photograph of UV-VIS spectrophotometer

III. EXPERIMENTAL DETAILS

3.1. Preparation of Dye Solutions

50 g of the leaves in Fig 3.1 were cut into small pieces first and grounded using motor and pestle for 30 min. After that, the powder was mixed with 50 ml of ethanol for 3 h and the solution was filtered by the paper filter. Fig 3.2 shows the natural dye solution. The colors of Henna, Teak and Burmese Ironwood are yellowish-orange, brownish-red and greenish-yellow respectively.[18]

Fig 3.1 Henna, Teak and Burmese Ironwood leaves

Fig 3.2 Natural dye solution

3.2. UV-VIS Spectroscopic Analysis

The point on the absorption spectrum of a solution which represents the minimum energy required for electronic transition from the valence band or HOMO (highest occupied molecular orbital) level to the conduction band or LUMO (lowest unoccupied molecular orbital) level is the absorption edge of the solution. The wavelength at the absorption edge can be used to calculate the energy band-gap of the solution. According to the absorbance spectra, all solutions have the same strong cut-off point with the same band-gap energy.

IV. RESULTS AND DISCUSSION

4.1 Optical Properties of Henna dye, Teak dye and Burmese Ironwood dye

The absorption photon of dye solution in the UV, visible and IR regions of solar spectrum is important for DSSC. So, the broader absorption band and the good matching of HOMO/LUMO levels of the dye with the bottom edge of conduction band of semiconductor and the redox potential of electrolyte give the high efficiency of DSSC. According to absorbance spectra and light harvesting efficiencies, high concentration gives the broader range of light absorption. Henna strongly absorbs the photons in UV and visible regions of the wavelength between 250 nm and 700 nm as shown in Fig 4.1. The strong cut-off point is at 690 nm and the band-gap energy of Henna is about 1.8 eV. The photons in UV, visible and NIR regions can be absorbed by Teak dye. The strong cut-off point is at 688 nm and the band-gap energy of Teak is about 1.8 eV. Burmese Ironwood can strongly absorb the violet color only in the visible region because of its yellowish-green color in appearance. On the other hand, Burmese Ironwood cannot strongly absorb the high energy photons in UV region as shown in Fig 4.5.

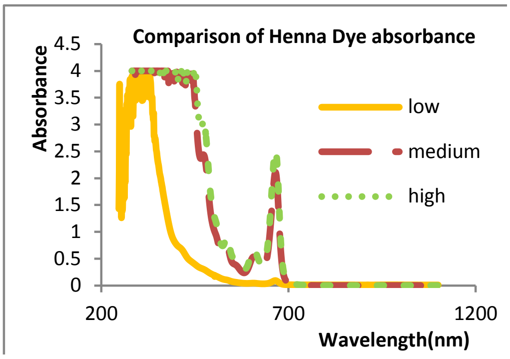

Fig 4.1 Absorbance spectra of Henna dye

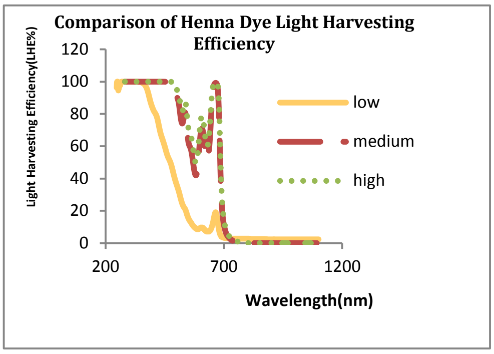

Fig 4.2 Light harvesting efficiencies of Henna dye

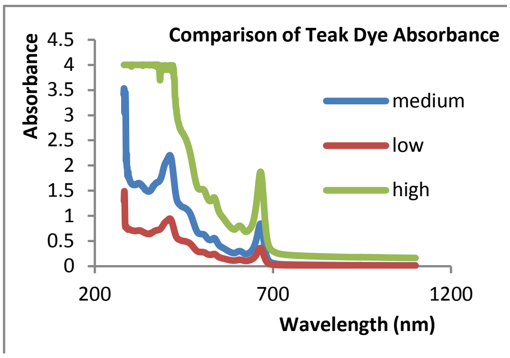

Fig 4.3 Absorbance spectra of Teak dye

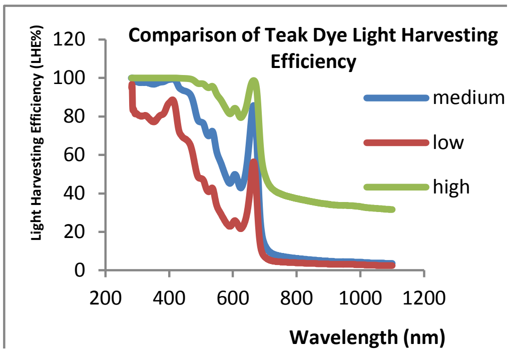

Fig 4.4 Light harvesting efficiencies of Teak dye

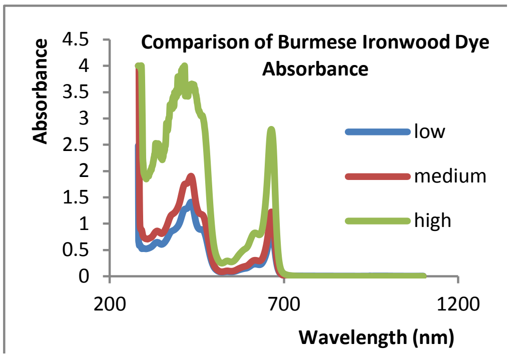

Fig 4.5 Absorbance spectra of Burmese Ironwood dye

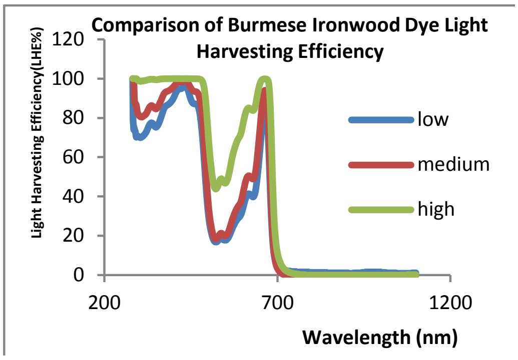

Fig 4.6 Light harvesting efficiencies of Burmese Ironwood dye

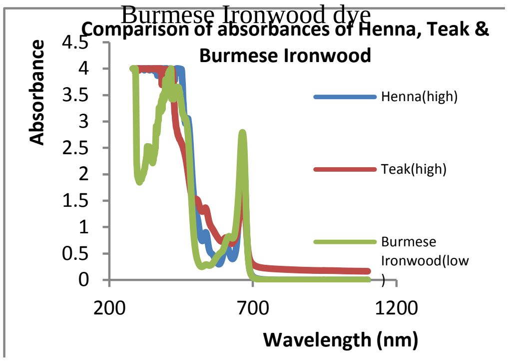

Fig 4.7 Absorbance comparison for three dyes

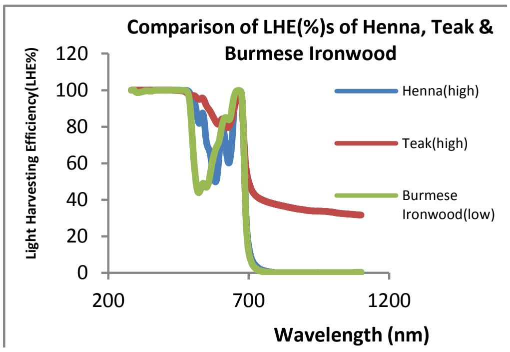

Fig 4.8 Comparison of light harvesting efficiencies for three dyes

V. CONCLUSION

The optical properties and the band-gap energy of dye solutions extracted from three leaves have been studied by UV-VIS spectroscopy. Broader absorption band is the key factor of dye solution in DSSC. In UV and visible region, Henna and Teak leaves strongly absorb the high energy photons. In Fig 4.8, Teak with high concentration shows broader absorption range and it can absorb the photons in NIR region. But Burmese Ironwood cannot absorb high energy photons in UV and visible region. According to the optical properties of dye solutions, dye with low concentration cannot absorb high energy photons, and high concentration gives high absorption photon. But high concentrated dye becomes more sticky and greasy, and causes series resistance R_s in DSSC. And then pH control should be made to increase the performance of DSSC. The efficiency of DSSC depends on the dye extracting temperature. But the temperature should not exceed the optimum value because of the decrease of the stability of anthocyanin at high temperature greater than the optimum value.

Since the strong cut-off point of all dyes is the wavelength of about 700 nm and the band-gap energy is 1.8 eV.

APPENDIX

Henna Tree

Teak Tree

Burmese Ironwood Tree

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