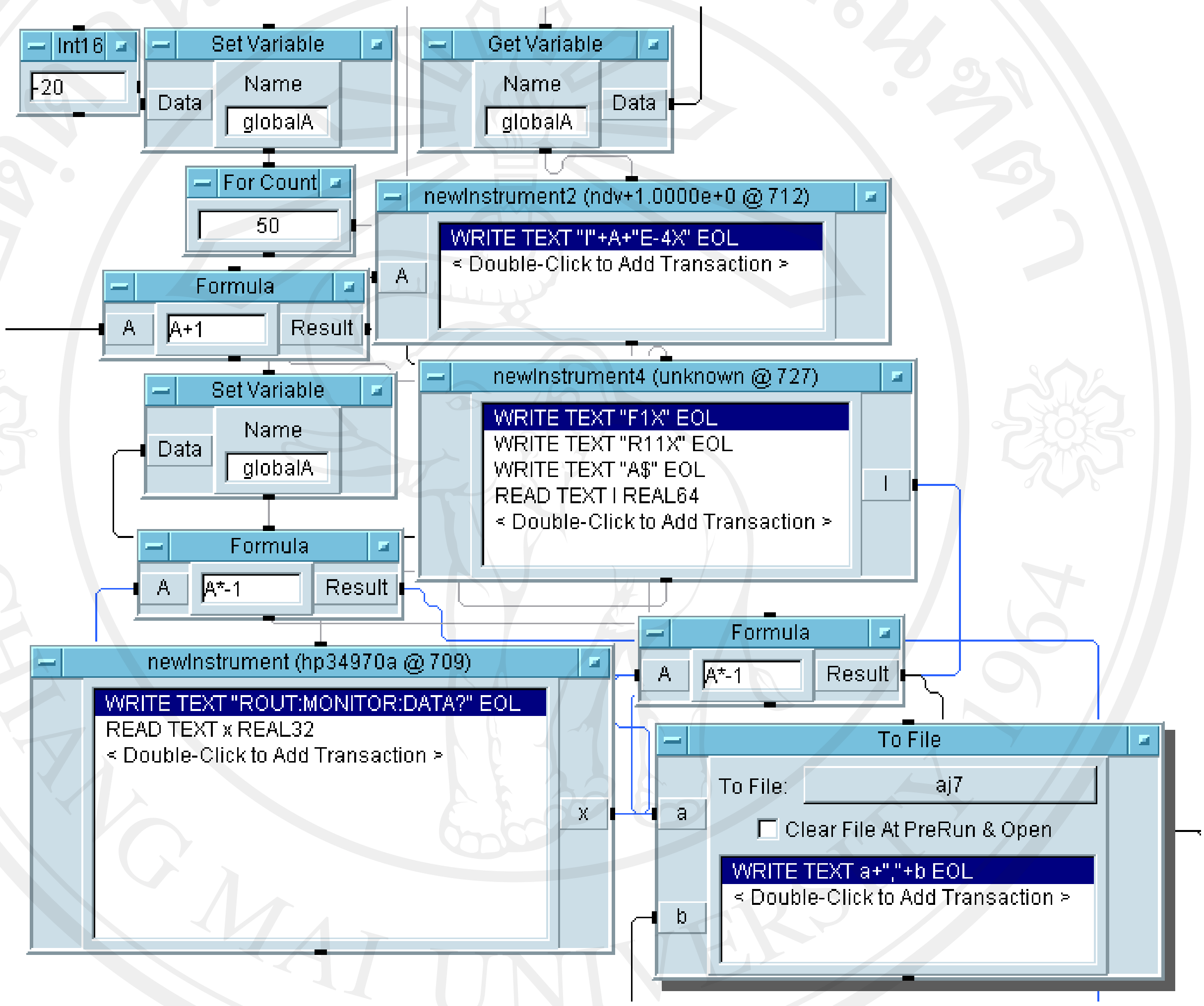
ภาคผนวก

ภาคผนวก ก

โปรแกรมคอมพิวเตอร์ที่ใช้ในการทดสอบประสิทธิภาพเซลล์แสงอาทิตย์



รูปที่ ก-1 แสดงโปรแกรมทดสอบประสิทธิภาพเซลล์แสงอาทิตย์

ภาคผนวก ข

นำเสนอผลงานแบบบรรยายในการประชุมวิชาการระดับประเทศ “SIAM PHYSICS CONGRESS 20011” จัดโดยสมาคมฟิสิกส์ไทย ร่วมกับมหาวิทยาลัยเทคโนโลยีพระจอมเกล้าธนบุรี ระหว่างวันที่ 23-26 ณ โรงแรมแอมบลาสเดอร์ซิตี้ จอมเทียน พัทยา ชลบุรี โดยมีรายละเอียดดังนี้

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Photoconversion Efficiency of Zinc Oxide Dye-sensitized Solar Cells Using Natural Dyes from Local Plants of Thailand

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Dye-sensitized solar cells are promising future clean energy. Usually, Ruthenium complex was used as dye in the TiO_2 dye-sensitized solar cells. However, Ruthenium complex is expensive due to rare material of Ruthenium. In this work, various natural dyes, such as *Basella rubra* Linn, *Dicerma biarticulatum* (L.) DC, and *Morus alba* L were investigated for ZnO DSSCs. The dye solutions were characterized optical properties by UV-Vis spectroscopy. The structure of ZnO DSSCs was FTO/ZnO/dye/electrolyte/Pt/FTO. For these DSSCs, ZnO in the form of nanoparticle and powder was used as an semi-conductor layer. The photoconversion characteristics of ZnO DSSCs were tested under simulated sunlight AM 1.5 came from a solar simulator with the radiant power of 100 mW/cm^2. It was found that DSSCs with *Dicerma biarticulatum* (L.) DC and ZnO nanoparticle yielded the highest photoconversion efficiency of 0.14% among the investigated natural dyes.

Keywords: Dye-sensitized solar cell; Natural dye; ZnO

1. INTRODUCTION

Dye-sensitized solar cells (DSSCs) are promising future clean energy which become popular and inexpensive [1]. Solar cell is a device for converting solar energy into electricity. The structure of DSSC composes of five main components: transparent conductive mechanical support, wide-band-gap semiconducting photo-electrode, dye sensitizer, redox couple electrolyte and Pt counter-electrode. The Ruthenium complex is mostly used as a dye for DSSC. According to the work from Gräzel group, they have used TiO_2 nanoparticle as photo electrode and ruthenium bipyridyl complexes as dye sensitizer. The results showed the significant progress with photoconversion efficiency up to 11-12% [2]. However, the ruthenium complex is rather expensive and rare material.

ZnO is one promising metal oxide semiconductor that could be used as photoelectrode in DSSC. This is due to its band gap, electron affinity, and electron injection effiency which are nearly the same as TiO_2 [3].

The natural dyes obtained from the fruit, flower and leaf of plants provide the variety of color from red to purple. These natural dyes can be extracted easily by a simple procedure. Photosensitizers for DSSCs from natural plants have been investigated by many researchers. In china, Hao et al. (2005) report the alcohol extraction of black rice, erythrina variegate flower, rosa xanthina flower, capsicum and kelp and also the dye refining by chromatogram method. The black rice extract gives the best photosensitized effect because the anthocyanin molecule in black rice extract perform the better absorption on TiO_2 porous film [4]. In Mexico, N.M GÓmez-Ortíz et al. (2010) have explored the use of dye extract from achiote-seed (*Bixa orellana*). The pigments of bixin and norbixin are obtained by separation and purification using chromatrograph. It has been reported that the highest efficiency comes out with the bixin-sensitized solar cell due to its highest light absorbance ability [5].

In this work, natural dyes extracted from *Basella rubra* Linn, *Dicerma biarticulatum* (L.) DC, and *Morus alba* L have been investigated in ZnO dye-sensitized solar cells.

2. EXPERIMENT

In this work, two types of ZnO: ZnO nanoparticle and ZnO powder were used as photo electrode. ZnO nanoparticle and ZnO powder paste were prepared by dissolved ZnO nanoparticle (purity of 99.5+%, ZoNoP) and ZnO powder (purity of 99.9%, Sigma Aldrich) in polyethylineglycol (PEG 20000, Sigma Aldrich) solution with ratio of ZnO:PEG equal to 1:1 by weight and stirring for 30 min. Next, the photoelectrode was fabricated by screening ZnO nanoparticle and ZnO powder paste on FTO glass and then heated at 400 °C for 1 h with a temperature rate of 5 °C/min under normal atmosphere to remove PEG. The film area was 0.5x0.5 cm^2. To prepare for the dye, the clean and dry *Basella rubra* Linn, *Dicerma biarticulatum* (L.) DC, and *Morus alba* L were finely ground and put into a 95 wt% ethanol solution with material:ethanol of 1:2 by weight. The dye solutions were kept in room temperature and avoided direct sunlight for 24 h to extract natural dye sufficiently. Then, the solid residues were filtered out. After that, the ZnO nanoparticle and ZnO powder on conductive glass were soaked in *Basella rubra* Linn, *Dicerma biarticulatum* (L.) DC , and *Morus alba* L organic dye solution for 24 h. The ZnO photo electrode and the Pt counter electrode (0.5 mM Hydrogen

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hexachloroplatinate(IV) Hydrate,Cl_6H_2Pt.aq, in acetone solution) were assembled together using a hot-melted double layer parafilm (50 μm thick/sheet). The structure of ZnO DSSCs was shown in Fig.1. In this study, each natural dye was investigated with ZnO DSSCs using ZnO nanoparticle and powder as a semi-conductor layer. The redox electrolyte (0.3 M LiI+0.03 M I_2 in polyethylene carbonate) was filled into the inter-space between the photo electrode and the counter electrode through two predrilled holes on the side of the device. The natural dyes and photoelectrode were characterized by using the UV-visible spectrophotometer (Varian Model Cary 50). The characteristic of DSSCs such as photocurrent, photovoltage and power conversion efficiency were determined under simulated sunlight using a solar simulator with the radiant power of 100 mW/cm^2 (xenon lamp with AM-1.5 filter). Standard Si solar cell was used to calibrate the incident light intensity. The photocurrent densities versus photovoltage (J-V) characteristics were measured with dc voltage and current source controlled by computer. The short current density (J_{sc}), open circuit voltage (V_{oc}), fill factor (FF), and overall power conversion efficiency (η) were then obtained from the J-V curve.

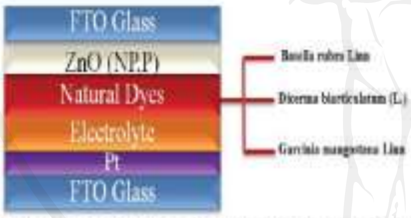


Figure 1. Structure of ZnO DSSCs. (FTO/ZnO(NP,P)/Natural dye/electrolyte/Pt/FTO)

3. RESULTS AND DISCUSSIONS

3.1 Optical properties.

3.1.1 Absorbtion of natural dye

Fig. 2 showed the UV-VIS absorption spectra of Basella rubra Linn, Dicerma biarticulatum (L.) DC, and *Morus alba L* in ethanol solution. The absorption maxima for Basella rubra Linn was expected at 547 nm, while for Dicerma biarticulatum (L.) DC, the maxima were at 488 and 532nm and for Morus alba L, the maxima were at 536 and 664nm. It can be obtained that Dicerma biarticulatum (L.) DC was the strongest absorbing dye, followed by Basella rubra Linn and Morus alba L, respectively.

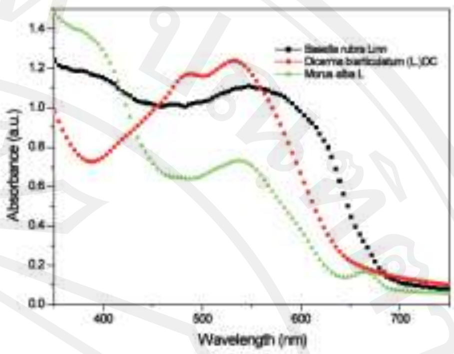
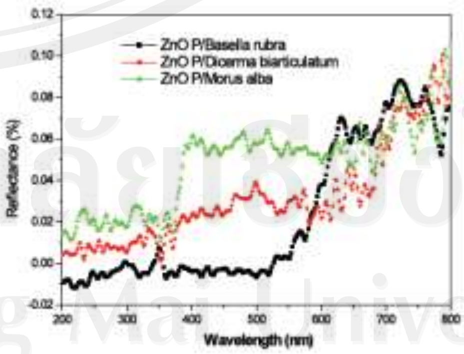


Figure 2. The absorption spectra of dye extraction from Basella rubra Linn, Dicerma biarticulatum (L.) DC , and Morus alba L in ethanol solution.

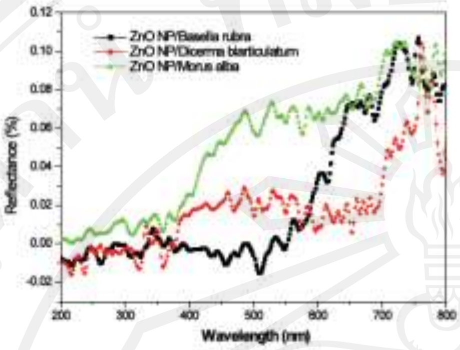
3.1.2 Reflectance spectra of photoelectrode

The reflectance spectra of photoelectrode prepared with ZnO powder substrate and soaked in natural dye for 24 h was shown in Fig.3(a). It can be seen that the dye molecules from local plants can absorp on surface of ZnO powder substrate photoelectrode. The highest absorptive ability was obtained from Basella rubra Linn, followed by Dicerma biarticulatum (L.) DC and Morus alba L, respectively.

The reflectance spectra of photoelectrode prepared with ZnO nanoparticle substrate and soaked in natural dye for 24 h was shown in Fig.3(b). The dye molecules from local plants can absorb on the ZnO nanoparticle substrate photoelectrode surface and the highest absorptive ability came from Basella rubra Linn, followed by Dicerma biarticulatum (L.) DC and Morus alba L, respectively. However, the dye from Dicerma biarticulatum (L.) DC was suitable for using in both ZnO powder and ZnO nanoparticle DSSCs due to its absorptive ability was not too high or too low.



(a) ZnO powder

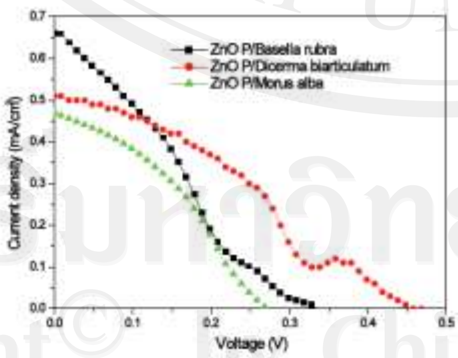


(b) ZnO nano particle

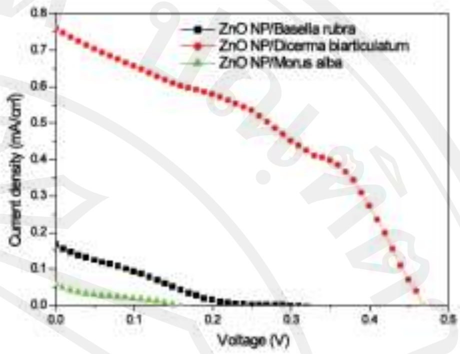
Figure 3. The reflectance spectra of photoelectrode prepared with ZnO Nanoparticle (a) and ZnO powder substrate (b).

3.2 Electrical properties.

In Figure 4, the *J-V* characteristic of the three DSSCs sensitized with Basella rubra Linn, Dicerma biarticulatum (L.) DC, and Morus alba L with ZnO nanoparticle and ZnO powder semiconducting photoelectrode were shown. The photoelectrochemical parameters such as short current density (J_{sc}), open circuit voltage (V_{oc}), fill factor (FF) and the overall power conversion efficiency (η) which determined from the J-V curves measurement were summarized in table 1. Clearly, the DSSC having ZnO nanoparticle electrode sensitized with Dicerma biarticulatum (L.) DC showed highest short current density of 0.76 mA/cm^2, and highest photoconversion efficiency of 0.14%



(a.) ZnO powder



(b.) ZnO nano particle

Figure 4. *J-V* characteristic of (a) ZnO powder and (b) ZnO nanoparticle DSSCs with different natural dyes

Table 1. Summary of the photoelectrochemical parameters such as short current density (J_{sc}), open circuit voltage (V_{oc}), fill factor(FF) and the overall power conversion efficiency(η) of DSSCs based on ZnO powder and ZnO nanoparticle substrates and the natural dye

Substrate	Type of Dye	J_{sc} (mA/cm^2)	V_{oc} (V)	FF	η (%)
ZnO P	Basella rubra Linn	0.66	0.33	0.26	0.057
	Dicerma biarticulatum (L.) DC	0.51	0.46	0.32	0.076
	Morus alba	0.47	0.27	0.36	0.046
	Eosin-Y	3.1	0.45	0.32	0.46
ZnO NP	Basella rubra Linn	0.17	0.29	0.19	0.009
	Dicerma biarticulatum (L.) DC	0.76	0.46	0.4	0.14
	Morus alba	0.06	0.15	0.23	0.002
	Eosin-Y	2.53	0.57	0.47	0.67

The efficiency of the DSSCs is correlated to the maximum absorbance of the natural dye.

4. CONCLUSION

Natural dyes extracted from local plants of Thailand such as Basella rubra Linn, Dicerma biarticulatum (L.)DC, and Morus alba can strongly absorb the visible light . So, they can be used as photosensitizer in dye-sensitized solar cells. The photoconversion efficiency correlated with the absorption peak and the absorptive ability of dye on the film photoelectrode on conducting glass. The highest conversion efficiency was obtained from the solar cell fabricated with ZnO nanoparticle using Dicerma biarticulatum (L.) DC dye extract, which is 0.14%, but this conversion efficiency was still low compare to the Eosin-Y. The low cell efficiencies might be a result of the overlap of the dye excited states and the metal oxide conduction band.

However, the use of natural dye as an alternative sensitizer for DSSCs is promising due to its simple preparation method, low cost and environmental friendly than the synthetic dye.

Acknowledgments

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ประวัติผู้เขียน

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