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Experimental Study on Potential use of Photochromic Thin Film as Energy Harvester

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ABSTRACT

This paper presents the application of design of experiments (DOE) in the characterization of the photochromic thin film after irradiation to UV light and designing of a circuit as a potential energy harvester. The results from this study suggest that exposure time at high level and interaction between exposure time and thickness of thin film have the largest influence on the mean voltage, while the thickness of thin film by itself does not affect the mean voltage. This study has provided a comprehensive knowledge and enhanced understanding for choosing the appropriate factors and levels in characterization of a photochromic film as a potential energy harvester.

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Background:

With continued technological advancement in a wireless technology and low power electronic application, power issues have gained greater attention amongst researchers. Many existing devices store power in a battery in the form of electrochemical energy. However the major disadvantage of this practice lies in its limited source of electrical energy and power supply. This problem has led researchers to develop an alternative energy harvester which will initiate electrical generation without a power supply.

Energy harvesting is a process of extracting energy from a surrounding environment then converting it into a usable form of electrical energy that can be used for another function. In the past, most energy harvesters use the existing energy harvesting system such as solar energy harvesting using photovoltaic cells (Rama, 2007). This study employs similar approach to solar energy harvesting but uses a different source of energy and system. To develop a new energy harvesting system, this study proposes an energy harvester system using photochromic thin film with UV light source.

Objective:

The objectives of this project are to electrically characterize the photochromic thin film after it is exposed to UV light and develop potential usage of the film as an energy harvester by designing a circuit. We examine the model using the well- known design of experiments (DOE) methodology for the selected input parameters. DOE is a statistical method that can be utilized to examine a model behavior to observe changes in parameters values which lead to different effects depending upon how the system components interact with each other.

Photochromic material changes colour upon absorption of UV light in response to electromagnetic radiation reversibly (Murvet, 2005). Molecules in the photochromic material are transparent in the absence of UV light and changes colour depending on the intensity of the UV rays. In the absence of UV light, the molecules in the material will return to its original colour. During the absorption of light, the material stores light in a form of heat energy that has potential to be converted into an electrical energy which has similar properties like a solar cell (Murvet, 2005). This material can be used as a means of transforming heat energy into an electrical energy that can be stored and used to power other devices. This paper presents the application of DOE in the characterization of the photochromic thin film after irradiation to UV light and designing of a circuit as a potential energy harvester.

MATERIALS AND METHOD

The photochromic dye used in this experiment, was 6-nitro BIPS (SP) as depicted in Figure 1. The

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experiments were implemented according to full factorial experimental design. Three variables were dye concentration, film thickness and exposure time. One response was selected in these experiments as shown in Table 1. Each variable was set at two levels, that is, a high level and low level. A total of eight different samples of photochromic thin film were prepared and the flowchart of the methodology is shown in Figure 2. The experiments were run in a random order with only one replicate. Randomization is necessary to minimize the effects of unexpected or uncontrollable changes (Paul, 2005). Photo irradiation was carried out by using a UV lamp (Efos Acticure A4000) as the excitation light source. Absorption spectra (response) were recorded after exposure to UV irradiations. The absorption of spectra or electron impact mass was measured on a fiber optic based UV-Vis spectrophotometer (Ocean Optics USB4000) equipped with xenon lamp (Najiah *et al*, 2013).

AC-DC rectifier circuit is used to convert an alternating current from ambient source of energy into a direct current. Voltage is measured from the samples directly after exposure time as shown in Figure 3. The samples were exposed to UV light for a certain amount of time at the same time the samples are connected to the AC-DC rectifier circuit as shown in Figure 4. The sample to be used as an input for the amplifier circuit was based on the most significant factors shown from the experiment.

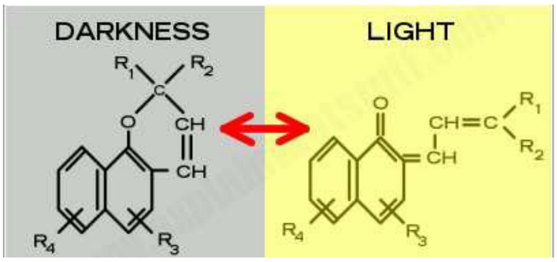

Fig. 1: Schematic diagram of photochromic compounds work.

Table 1: Experimental design generated using Minitab.

Standard order	Run order	PtType	Block	Dye concentration	Thickness (mm)	Exposure time (sec)
8	1	1	1	2	0.002	500
6	2	1	1	1	0.002	500
1	3	1	1	1	0.0015	300
4	4	1	1	2	0.0015	500
7	5	1	1	2	0.002	300
2	6	1	1	1	0.0015	500
5	7	1	1	1	0.002	300
3	8	1	1	2	0.0015	300

Table 2: Experimental plan and the responses of full factorial design.

Standard order	Run order	PtType	Block	Dye concentration	Thickness (mm)	Exposure time (sec)	Voltage (V)
8	1	1	1	2	0.002	500	0.008
6	2	1	1	1	0.002	500	0.004
1	3	1	1	1	0.0015	300	0.012
4	4	1	1	2	0.0015	500	0.007
7	5	1	1	2	0.002	300	0.013
2	6	1	1	1	0.0015	500	0.005
5	7	1	1	1	0.002	300	0.016
3	8	1	1	2	0.0015	300	0.006

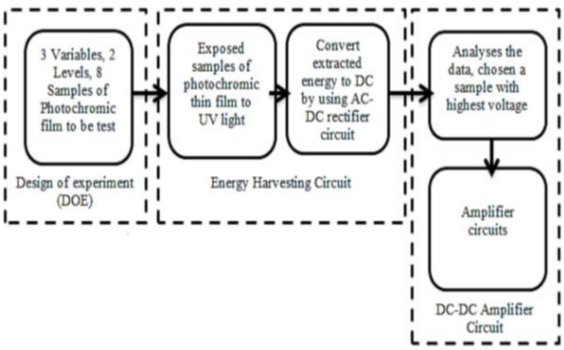

Fig. 2: Flow chart of the methodology .

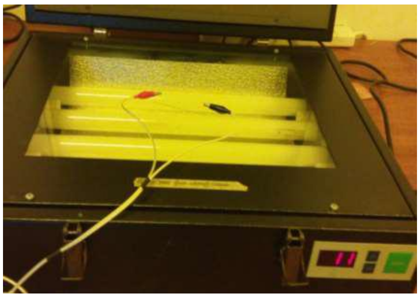

Fig. 3: After exposure to UV light for a certain amount of time, the sample it electrically measured to obtain its voltage.

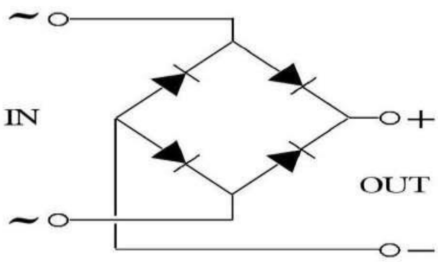

Fig. 4: AC to DC Rectifier Circuit.

Table 3: Analysis of Variance (ANOVA).

Source	DF	SeqSS	Adj SS	Adj MS	F-value	P-value
Dye Concentration (M)	1	1.51 E-05	1.51 E-05	1.51 E-05	121	0.058
Thickness (layer)	1	1.1 E-06	1.1 E-06	1.1 E-06	9	0.205
Exposure Time (seconds)	1	6.61 E-05	6.61 E-05	6.61 E-05	529	0.028
Dye concentration* Thickness	1	3.1 E-06	3.1 E-06	3.1 E-06	25	0.126
Dye concentration* Exposure Time	1	1.51 E-05	1.51 E-05	1.51 E-05	121	0.058
Thickness* Exposure Time	1	2.81 E-05	2.81 E-05	2.81 E-05	225	0.042
Error	1	1 E-07	1 E-07	1 E-07		
Total	7	0.000129				
S = 0.000353553 R-Sq = 99.90% R-Sq(adj) = 99.32%						

RESULTS AND DISCUSSION

Results from the analysis of variance (ANOVA) are displayed in Table 3. Before further interpretation of the analysis, the model residuals are checked for model inadequacies. In Figures 5 and 6, the plots of residuals against the predicted or fitted values and a normal plot are employed to assess the validity of the model assumptions. The plot of residuals against the fitted values as given in Figure 5 exhibiting structure less residuals verified that the normal assumptions constant variance and randomly scatted points are valid and therefore the model is adequate. This is further emphasized by the plot of residuals against the normal plot in Figure 6. The two plots confirm that the assumptions about the residuals are satisfied.

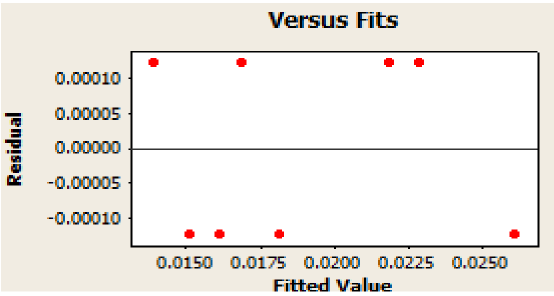

Fig. 5: Residue versus fit plot.

The data is analyzed by first plotting the main effect estimated as shown in Figure 7 using Minitab. This effect could easily be calculated based on contrast effect (Kacker and Shoemaker, 1986) as given in equation below.

Dye concentration, A = $\bar{y}_{A^+} - \bar{y}_{A^-}$

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$$= \frac{ab+b}{2n} - \frac{a+(1)}{2n} \qquad = \frac{1}{2n}[ab + b - a - (1)]$$

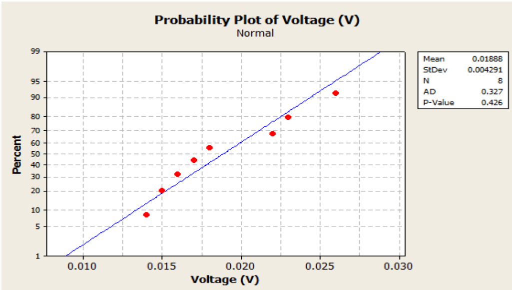

Fig. 6: Probability plot of voltage.

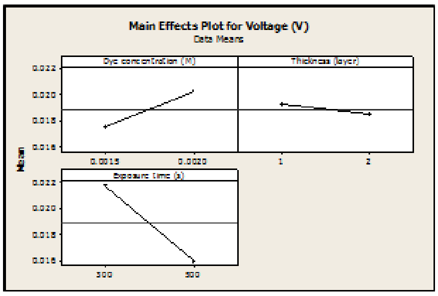

Fig. 7: Main effect plot for voltage.

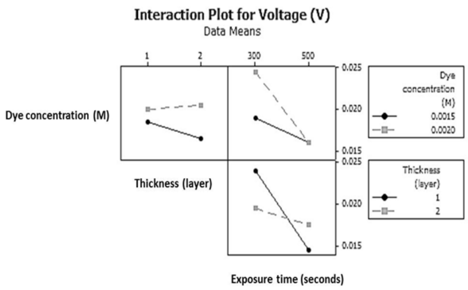

Fig. 8: Interaction plot between variables.

The contrast for estimating any effect, simply multiply the signs in the appropriate column of the table by the corresponding treatment combination and add. These results suggest that dye concentration would be set at high to increase mean voltage, film thickness at low and exposure time at high. This plot shows that exposure time has the largest effect, next dye concentration and film thickness, which is also observed in Table 3.

Examination of the data in Table 3 revealed that one of the main effects or factors, exposure time was found statistically significant with p-value of at 0.028. While the main effect dye concentra-tion was marginally significant at a p-value of 0.058, the main effect layer thickness is not statistically significant at p-value of 0.205. This confirms our initial interpretation of the data based on the magnitudes of the factor effects. Analysis of unreplicated factorial design, most high-order interactions are negligible due to sparsity of effects principle (Myers *et al.*, 1992).

if we considered only these main effects, we would run dye variable at high, and thin film and exposure time at low to maximize the voltage. However there is a strong interaction between film thickness and exposure time for this experimental design with p-value 0.042. The main effects do not have much meaning when they are involved in significant interactions.

Therefore this indicates that the interaction is statistically, highly significant. There is no significant interaction between the dye concentration and thickness of film with p-value of 0.126. This suggests that there is some evidence that these factors and interaction have influence on the voltage. Based on results from Table 3, the exposure time is the most significant factor with p-value 0.028. The dye concentration is fairly significant with 0.058 p-value and lastly the film thickness is not a significant factor in this experiment with p-value 0.205. Though Figure 8 shows the interaction between the dye and

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the film thickness, both variables were insignificant and their effect are small and negligible.

Conclusion:

Based on results presented in this paper, the exposure time is the most significant factor with p-value 0.028. While the dye concentration is fairly significant with 0.058 p-value, film thickness is not a significant factor in this experiment with 0.205. A sample with combination of low concentration, 300 second exposure time and 1 layer thickness is chosen as an input for the amplifier circuit as it showed the highest voltage reading and found to be the most significant variables. Based on the research conducted, comprehensive knowledge has been learnt on the potential used of photochromic material as it exhibited electrical characteristic in the possible for such designs.

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