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Fabrication and Characterization of Banana Flower Extract Anthocyanin-Based Organic Solar Cell

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***Abstract*—Fabrication and characterization of organic solar cells with layer structure of ITO/PEDOT: PSS/PEG/PEG+Anthocyanin/Anthocyanin/Al/ITO using banana flowers as electron acceptors have been done successfully. The electrical properties, absorbances, surface structures, and anthocyanines are characterized completely. The deposition of each layer of PEDOT:PSS, PEG, and anthocyanin is made using spincoating, whereas aluminium is metallized by thermal evaporation method using *LADD Research Industries* evaporator. The electrical properties of organic solar cells are determined under illumination of xenon lamp1000 W/m^2 using Keithley 2602A*system sourchMeter* in active area of 1 cm^2. The efficiency of organic solar cell measured is 1,03 x 10^{-4}%.**

***Index Terms*—anthocyanin, banana flower extract, organic solar cell**

I. Introduction

The active materials used to fabricate conventionally anorganic solar cell are anorganic semiconductor materials such as silicon (Si), galium arsenide (GaAs), and cadmium sulfide (CdSe) [1]. The measured conversion efficiency of anorganic solar cell generally achieves 20% in which the best performance is made of thin layers and multijunctions of anorganic solar cell devices, inversely for the best heterojunction organic solar cell achieves efficiencies of 3,0-3,5% [2], [3]. Nevertheless, the fabrication process of anorganic active materials-based solar cell thin films are made using epitaxy method, the operation cost is expensive, therefore a new solution is welcome for it.

Organic solar cell is a device for light conversion efficiency into elecrical energy which consists of organic active layer existed between transparent and metal elecrode. Based on their device structures, the organic solar cells can be classified into single layer, bilayer, blend, and laminated solar cell. In general, the development of organic solar cell aims to achieve higher solar cell efficiency through the separation process and the collecting of electrical charges on the active layers of polymer, pigmen or dye [4].

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The organic solar cell consists of transparent cathode, an active layer to transmit and absorb light. The polymer active layers are made of conjugated film mixture (as electron donors and small molecule acceptors) [5]. The banana flower extract is available as an alternative of active materials for organic solar cell development, anthocyanin is expected found in a certain amount in banana flowers [6]. The used polymer as a light-absorbing material is banana flower extractanthocyanin which does also act as an electron-donating (i.e., hole accepting) component in active layer (Fig. 1) inside corresponding solar cell geometry.

Anthocyanin is a flavonoid, part of phenolic compound, and a chlorophyl which is distributed widespread in whole parts of plant due to pigmen content which can give colour on high plant and soluble in water [7]. Anthocyanin is highly potential available as solar cell active material due to it has light absorption spectrum in the relatively long range namely from red to blue.

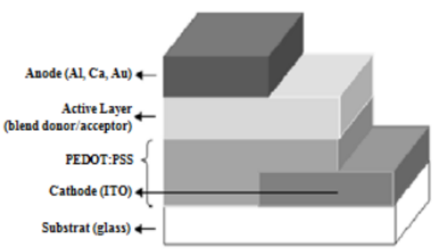

Figure 1. Layer structure of bulk heterojunction of organic solar cell.

The fabricated organic solar cell consists of four layers, excluded it's glass substrate. On the glass substrate, ITO cathode is placed, a cathode of high transparent material, and glass substrate is coated by ITO. A mixture of PEDOT:PSS conductive polymer or poly (3,4-ethylenedioxythiophene):poly(styrenesulfonate)seems as shown in Fig. 1. The PEDOT:PSS conductive layer has some functions, not only as hole transport and barrier exciton but also for smoothing ITO surface, protecting active layer from oxygen, and protecting material cathode in order no diffusion into active layer [3]. The organic solar cell active layer is fabricated of mixture of conjugated polymer (donor) and fullerene (acceptor)

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which absorbs incident light. The effective conjugation length plays an intensive role in controlling the solar cell efficiency [8].

The light absorption process causes exciton can return to ground state or split into electron and hole. On the active layer, one of anode materials (aluminium, silver or gold), is deposited.

The work process of organic solar cell includes three steps, namely (a) light (photon energy) absorption, (b) the separation of charges (electrons and holes) on the surface between donor-acceptor, and (c) the flow occurence of both charges inside organic material to both electrodes. The requirement to achieve high efficiency of transfer process of photon energy into electrical current is no recombination between electron and hole before the flow to external circuit occurs. To decrease recombination process of electron-hole, electrons and holes are carried by different materials. For donor-acceptor device, acceptor material has good electron conductivity. Inversely, for donor-acceptor device, acceptor material has good a hole conductivity [9].Therefore, the organic materials which can easily produce electron-hole pair and high charge mobility play key role in determining organic solar cell efficiency.

II. Materials and Method

Materials used in this research comprise of banana flower extract, technical ethanol (C_2H_5OH) 96%, technical acetid acid (CH_3COOH), distilled water, glass substrate indium tin oxide 8-12 Ω/sq (Aldrich), poly (3,4-ethylenedioxythiophene): poly (4-styrenesulfonate)/PEDOT: PSS (Aldrich Cat. 483095) solution, polyethileneglycol/PEG 99% (Merck KGaA), and aluminium (Al) 99,95%.

The banana flower anthocyanin is made into 5 mass fraction variations where solvent mass of 124 g is fixed for each mixture. The used solvent is a mixture of ethanol, acetate acid, and distilled water in ratio 25: 1: 5.

First, banana flowers are sliced in cubic form, crushed using blender (COSMOS CB-285G) in solution for 2 minutes, filtered using wide hole filter paper, and then distilled. The resulted distillates are filtered using smooth filter paper and the solution is concentrated using magnetic heated stirrer (HMS-79) at temperature of 82^{o}C. Next, the anthocyanin of banana flower is bottled suitable with their sample codes.The banana flower extraction data based on the mass fraction variation is tabulated in Table I.

TABLE I. Extraction Data of Banana Flowers.

Sample codes	Mass fractions	Banana flower masses(g)	Solution masses (g)
A	0,2	31	124
B	0,3	62	124
C	0,4	83	124
D	0,5	124	124
E	0,6	186	124

Fabrication of ITO/PEDOT:PSS/PEG/PEG+Anthocyanin/Anthocyanin/Al/ITO organic solar cell is initially done by preparing indium tin oxide (ITO) substrate 1,5 cm x 1 cm in size. The ITO substrate is cleaned respectively in ethanol, distilled water, and ethanol using ultrasonic cleaner bath each for 15 minutes and then dried using oven at 100^{o}C for 10 minutes.

On the ITO substrate, PEDOT:PSS film is coated using spincoating method (*spin coater,* cit wr05) at rotation speed 600rpm for 1 minute, then it is heated using oven at temperature of 100^{o}C for 10 minutes. On the PEDOT:PSS layer, polyethylene glycol is deposited at 600rpm speed for 20 seconds, then heated using oven at temperature of 100^{o}C for 20 minutes. The mixture of PEG and anthocyanin is spincoated at 600rpm speed for 30 seconds at temperature of 200^{o}C for 10 minutes. The layer of banana flower anthocyanin is laminated on the layer of PEG and anthocyanin mixture using spincoater at 2600rpm for 30 seconds, next it is heated using oven at temperature of 200^{o}C for 15 minutes. The aluminium foil is thermally evaporated on the ITO substrate (*LADD Research Industries* evaporator). The electrical properties of thin films of banana flowers are characterized using I-V meter V1.0 ELKAHFI 100 with two point probe method and input voltage up to 4 Volt. Their microstructures and optical properties are observed using *Scopeman Digital CCD Microscope* MS-804 and *Ocean Optic* Vis-NIR USB 4000, respectively.

III. Results and Discussions

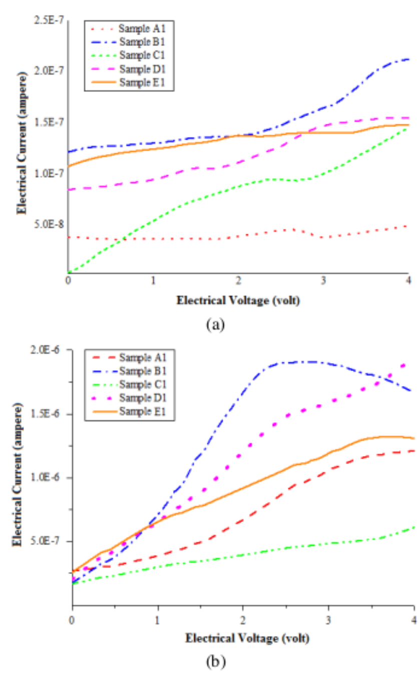


Figure 2. Graph of relation between voltages with electrical currents of banana flower anthocyanin thin films in different five mass fractions under: (a) dark and (b) light illumination condition.

As depicted in Fig. 2, each sample of the banana flower anthocynanin has different I-V response curve on the dark and light exposed condition. Under dark condition, the highest current measurement of sampleB1 achieves 2,14E-07A. The current increase on the sample B1 is highest compared others namely 1,91E-06A andbased on the calculation, the highest average of electrical conductivity is achieved by the sample B1 namely 2,56E-05A. Under dark condition, the measured current of the sample A1 is found the lowest current, while under light illuminated condition the measured current of sample A1 is known higher than C1, nevertheless a consistency of electrical current increase on the each sample afterlight exposure is created. The larger amount of light absorbing anthocyanin molecules the larger amount of anthocyanin molecules move and the larger the produced current.

In Fig. 3, a graphis shown to determine a relationship between wavelengths and absorbances of banana flower extract thin films in five mas fractions,their wavelengths are in the range of 350-700nm. It means banana extract flowers have wide absorbance spectrum ranges, from violet to red spectrum. The absorbance of a compound for certain wavelength will increase if the amount of molecules experiencing transition increases. The high absorbance of light on the banana flower thin film shows the anthocyanine molecules which experiencing transition increase too. The sample A2 has highest maximum absorbance namely 1,58 on the wavelength of 404,41nm with highest absorbance spectrum range of 350,02-1043,01nm.

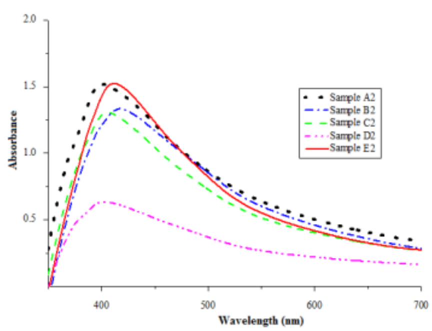


Figure 3. Graph of wavelengths related to absorbance levels of banana flower anthocyanins in different five mass fractions.

TABLE II. PERFORMANCE OF OPTICAL PROPERTIES OF THIN FILMS OF BANANA FLOWERS.

Mass fractions	Sample codes	Ranges of wave spectrum (λ, nm)	Wavelengths on maximum absorptions (λ_{maks}, nm)	Maximum absorptions (A_{maks})
0,2	A2	350,02 - 1043,01	404,41	1,580
0,3	B2	351,75 - 1024,04	408,04	1,348
0,4	C2	351,75 - 1040,59	404,41	1,325
0,5	D2	351,75 - 1040,59	402,70	0,641
0,6	E2	353,05 - 1024,53	408,89	1,559

Table II informs that the highest maximum light absorption (1,580) occured on wavelength of 404,41 nmfor sample A2. Based on the maximum absorption wavelength, sample E2 has maximum absorption (1,559) on wavelength of408,89nm, this means the energy required for electron transition is lower than other samples, due to the molecules those need more energy will absorb shorter light, whereas the molecules those need smaller energy for transition will absorb longer wavelength light.

The microstructures of banana flower anthocyanin thin films are investigated to determine their surface structures and homogenities. Microscope images of banana flower anthocyanine thin films in magnification of 2400x are shown in Fig. 4.

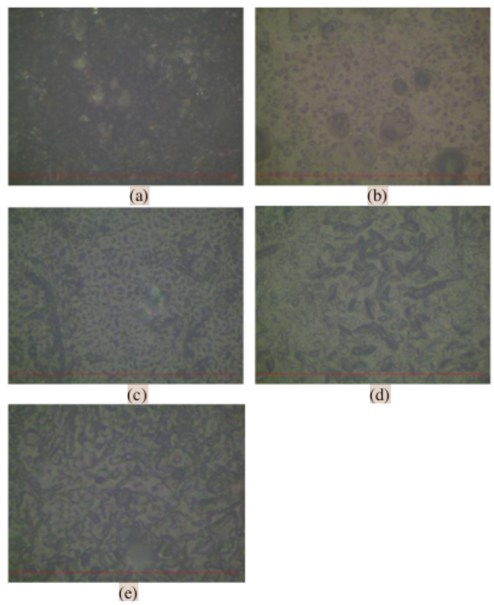


Figure 4. The microstructures of banana flower anthocyanin thin film samples: (a) A34, (b)B34, (c) C34, (d) D34, and (e) E34.

The surface structures of D34 and E34 samples seem more homogeneous than those of A34, B34, and C34. The samples of C34, D34, and E34 have the same surface structures, whereas the samples of A34 and B34 have different surface structure. The smallest grain size is sample A34 and the biggest one is E34.

The content of banana flower anthocyanin is characterized using *PerkinElmer Frontier* FT-IR *Spectroscopy*. This characterization aims to confirm existence of banana flower anthocyanin content based on the wavenumbers of 4000-500 cm^{-1} on the FTIR spectra as shown in Fig. 5, to identify functional group, and to measure transmitance of banana flower anthocyanine of each sample. The characterization is done by means smearing banana flower anthocyanine on the KBr pellet.

The samples are organic compounds that include C, O and H elements. Fig. 5 shows FTIR spectrum of banana flower anthocyanins of A, B, C, D and E sample. The peak of first wave at all samples inform there is suitability with stretching vibration of hydroxil group O-H bond of phenolic [10]. The second peak shows an existing stretching vibration of C-H bond. The third spectra peaks of A, B, C, and D show existing C≡C bonds. The fourth peak shows the stretching vibration of C=C double bond which can correlate to anthocyanin C=Caromatic compound such as anthocyanine of *Rhododendron* flower with wavenumber of 1630 cm^{-1} which is a infrared spectra of C=C [11] and there is a weak bond on A and B sample. The fifth peak shows C-H bond originates from the use of geminalor gem-dimetil (two metil groups of same carbons). The sixth peak give an information about an existence of the stretching vibration of C-O bond of ester. The seventh peak indicates a bending vibration of C-O bond of eter, and the last spectra peak shows C-H bond of alkene group [10]. Based on the FTIR characterization of five samples, it can be concluded that those samples contain anthocyanin.

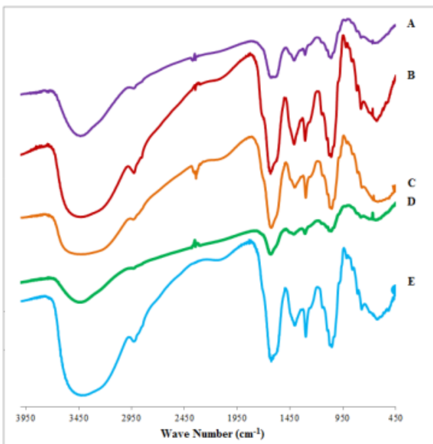


Figure 5. Graph of banana flower anthocyanin FTIR spectra in different five mass fractions.

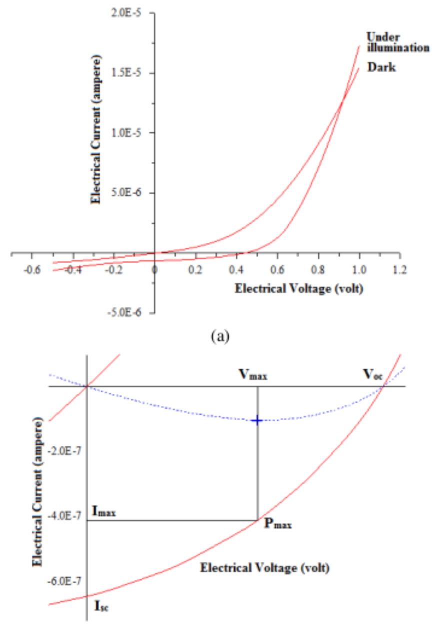
The performance of organic solar cell can be determined through I-V characterization. Fig. 6 exhibits measurement results of electrical properties of ITO/PEDOT:PSS/PEG/PEG+Anthocyanin/Anthocyanin/ Al/ITO organic solar cell using Keithley 2602A *system sourchMeter* under dark condition and under Xe lamp illumination of 1000 W/m^2 intensity. That graph also informs a difference of I-V response on dark and light condition.

Based on the I-V characterization, P-N junction of device is formed. This is shown by a graph of current relation to voltage with diode curve bend. On the forward biased-operated diode, the depletion layer in the P-N junction will shorten due to the effect of given external voltage difference, so that barrier potential will decrease as well as given exteral difference increases. The decrease of this barrier potential causes the charge carriers diffuse. The generated current will increase exponentially respect to the increase of given external potential difference.

Based on the electrical characterization as graphed in Fig. 6, open circuit voltage (V_{oc} = 0,43 Volt), short circuit current (I_{sc} = 0,645 μA), maximum voltage (V_{max} = 0,25 Volt),and maximum current (I_{max} = 0,413 μA) are available to calculate fill factor(FF) and organic solar cell efficiency (η) with cell active area of 1 cm^2. The calculated FF and η of fabricataed solar cell include 0,37 and $1{,}03x10^{-4}$%, respectively.

IV. Conclusion

In conclusion, the organic solar cells have been succesfully fabricated of banana flower extract-based active materials. Efficiency achieved of fabricated succesfully organic solar cell is 1,03 x 10^{-4}. A different I-V response of fabricated organic solar cell is found under dark and light illmuniation condition. This means the fabricated device can work well.



(b)

Figure 6. (a) Curve of I-V organic solar cell under dark and light illumination condition; (b) A way in determining V_{max}, I_{max}, V_{oc}, and I_{sc} paramater.

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PAGE 1

PAGE 2

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PAGE 4

PAGE 5