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Effect of Illumination on the Photovoltaic Parameters of Al/p-Si Diode with an Organic Interlayer Prepared by Spin Coating Method

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Illumination,
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Capacitance

Abstract: In this study, the photovoltaic device application of bromothymol blue (BTB) as an organic interlayer has been reported. After Al back contact fabrication on the surface of the chemically cleaned substrate by thermal evaporation method, the organic interlayer has been grown on p-Si substrate via spin coating technique. Al top contacts have been formed on this organic thin film to finalize the device constructions. The different illumination intensities were exposed to the prepared sample for the enhancement in the photovoltaic properties of device. The fundamental photovoltaic parameters such as open circuit voltage (*Voc*), short circuit current (*Isc*) and output power (*P*) were determined for the device under different illuminations. The photocurrent and the photo voltage have been increased with the increasing in illumination intensity. The dependence of the capacitance on the voltage at high and low frequency has been also reported for the studied device. Consequently, it has been confirmed that the illumination intensity has an important influence on the photovoltaic parameters of the device.

Spin Kaplama Yöntemiyle Hazırlanan Organik Arayüzeyi İçeren Al/p-Si Diyotunun Fotovoltaik Parametreleri Üzerine Aydınlanmanın Etkisi

Anahtar Kelimeler
Aydınlanma,
Organik arayüzey,
Fotovoltaik,
Kapasitans

Özet: Bu çalışmada, organik ara yüzey olarak brom timol mavisi (BTB) kullanılarak foto voltaik aygıt uygulaması rapor edilmiştir. Kimyasal olarak temizlenen tabanın mat yüzeyine ısıl buharlaştırma yöntemiyle Al arka kontak oluşturulduktan sonra, dönel kaplama yardımıyla organik ara yüzey tabakası Si taban üzerine kaplanmıştır. Aygıt üretimini tamamlamak için, bu organik ince filmin üzerine Al üst kontaklar oluşturulmuştur. Aygıtın foto voltaik özelliklerini iyileştirmek amacıyla hazırlanan örnek farklı şiddetlerdeki aydınlamaya maruz bırakılmıştır. Farklı aydınlanmalar altında aygıtın açık devre voltajı (*Voc*), kısa devre akımı (*Isc*) ve çıkış gücü (*P*) gibi temel güneş pili parametreleri belirlenmiştir. Aydınlanma şiddetinin artması ile fotoakım ve fotogerilim değerleri artmıştır. Ayrıca, yüksek ve düşük frekans değerlerinde aygıt sığasının voltaj bağımlılığı rapor edilmiştir. Aydınlanma şiddetinin üretilen aygıtın fotovoltaik parametreleri üzerinde önemli bir etkisinin olduğu sonucuna varılmıştır.

1. Introduction

Recently, organic interlayer has been great interest in the field of organic electronics, because of its possible device application such as organic light emitting diode, photodiode, optical sensor and solar cell in optoelectronic technology [1-10]. Among the organic materials, the azo dyes having with the aromatic azo compounds are the most common used photoactive materials due to their good optical properties [4]. These dyes can be used in switching and optical data storage technologies [4].

Organic thin films have been easily prepared on any substrate via different techniques such as the thermal evaporation, the chemical bath deposition, the dip coating and the spin coating [11-19]. Spin coating technique was preferred among them, because it is cheaper and simpler growing methods than the others. In this study, bromothymol blue (BTB) with molecular formula $C_{27}H_{28}Br_2O_5S$ and UIPAC name

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4,4′ - (1, 1- Dioxido -3H-2, 1 - benzoxathiole -3,3 - diyl) bis (2 – bromo - 6 isopropyl -3- methylphenol) was chosen as an organic material due to its properties such as an easy of synthesis, good solubility in water and alcohol. In our previous study, it has been reported the electrical parameters of Al/BTB/p-Si heterojunction via current – voltage measurement [2]. But, there is a little amount of information about the photovoltaic application of this organic compound.

The aim of this study is to analyze the photovoltaic characteristic of heterojunction based on BTB and to determine its photovoltaic parameters depending on illumination intensity.

2. Material and Method

For the fabrication of the heterojunction based on BTB ($C_{27}H_{28}Br_2O_5S$), the precursor solution was prepared as reported in literature [2]. The back contact of the heterojunction was formed by evaporation of Al metal, followed by thermal treatment at 570 °C during 3 min. In order to avoid the oxygen layer formation, immediately the BTB thin film was grown on cleaned p-Si substrate by spin coating unit. And then, Al circular top contacts with the diameter 1.5 mm were formed on the obtained organic interlayer/p-Si structure in vacuum system at the pressure of ~10^{-6} Torr. The current voltage measurements of diode were carried out at room temperature using Keithley 2400 sourcemeter in dark and helping a Newport 96000 simulator with AM 1.5G filter under various incident light power. The frequency dependent capacitance measurements were performed via HP Agilent 4294A impedance analyzer.

3. Results and Discussions

The voltage dependent current measurements were performed to investigate the influence of incident light power on the solar cell parameters of the device. The current at forward bias regime didn't change, while that of reverse bias region remarkably enhances with the incident power [3,19]. This indicates the generation of free carriers resulted by the absorption of incident photon energy, and these carriers contribute to the photocurrent at reverse bias. Illumination dependent photo current vs. photo voltage plots of heterojunction based on BTB are shown in Figure 1. As seen in the figure, photocurrent and the photo voltage enhances with the illumination power. The fundamental solar cell parameters such as short circuit current I_{SC}, open circuit voltage V_{OC} were determined for the heterojunction based on BTB with various incident light power, and given in the Table 1.

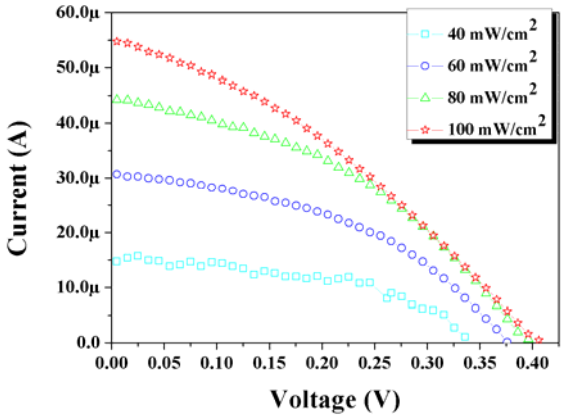

Figure 1. Illumination dependent photo current vs. photo voltage plots of heterojunction based on BTB

The plots of the output power vs. voltage for heterojunction based on BTB with increasing illumination intensities are shown in Figure 2. The electric power increases with the increasing of the voltage, and reaches to the maximum value of power, and then diminishes at the high voltages. The maximum value of the power (P_m) is estimated by the multiplication of the values of maximum current (I_m) and the maximum voltage (V_m) for each illumination intensities. The Figure 2 and Table 2 show that the values of P_m are shifted to the lower voltage when the incident light intensity increases. The light sensitivity of the device at -2 V was extracted. As seen in Table 1, the values of estimated parameters of heterojunction are not suitable for the solar cell application, but it is good enough for photodiode, optical sensor application [6].

Table 1. The values of V_{OC}, I_{SC} and light sensitivity under various illumination intensities for *Al/BTB/p-Si* structure

Illuminations (mW/cm²)	V_{OC} (mV)	I_{SC} (µA)	Light Sensitivity (Times)
40	347	14.69	239.59
60	375	30.69	517.29
80	395	44.28	770.59
100	407	54.78	1028.85

Figure 3 represents the dependence of I_{sc} and V_{oc} on different illumination (L) intensities for the heterojunction based on BTB. It is seen from this figure that both I_{sc} and V_{oc} vary almost linearly with the intensity of illumination for the studied diode. It is seen that photovoltage is only proportional to the incident light power [6,14]. Similar results were reported by Soylu et al. [16]. They fabricated p-Si heterojunction based on graphene oxide, and investigated the influence of light intensity on the photodiode parameters. They have reported to be the almost linear increment in V_{oc} with the incident light power.

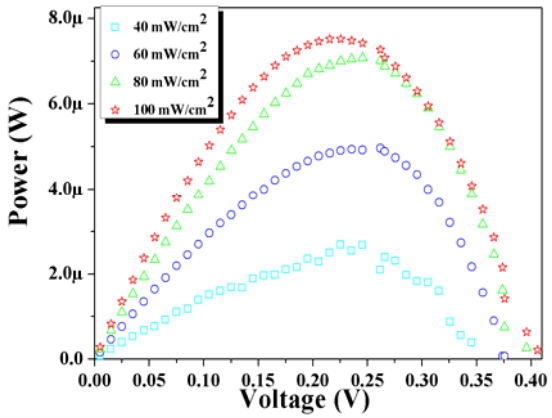

Figure 2. Illumination dependent the output power vs. voltage plots of heterojunction based on BTB

Table 2. The values of V_m, I_m, P_m and R under various illumination intensities for *Al/BTB/p-Si* structure

lluminations (mW/cm²)	V_m (mV)	I_m (μA)	P_m (μW)	R (A/W) (x10⁻⁴)
40	247	10.87	2.68	3.96
60	245	20.04	4.91	5.69
80	236	29.88	7.05	6.36
100	226	33.31	7.53	6.79

Furthermore, the relationship between V_{oc} and I_{sc} is almost linear for the heterojunction based on BTB as seen in Figure 4. These findings obtained from figures 3-4 indicate that the studied structure has good photo response characteristics even if having the poor solar cell efficiency.

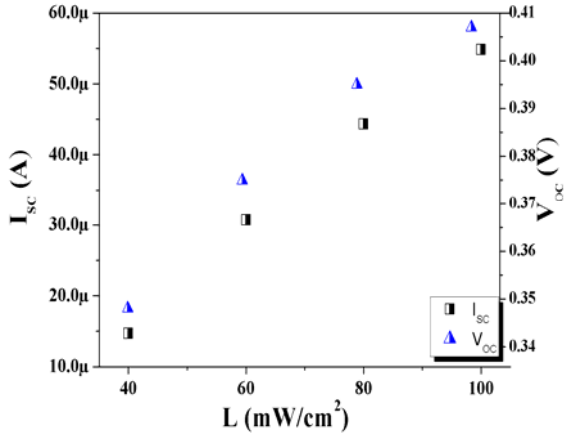

Figure 3. Dependence of I_{sc} and V_{oc} on different illumination intensities for heterojunction based on BTB

In order to provide detailed information about the photo sensing property of the studied device, the photocurrent as a function of incident light intensity is investigated using the relation [15];

$$I_{PH}=AL^{\alpha} \quad (1)$$

where I_{PH} is the photocurrent, A is a proportionality constant, L is the illumination intensity and α is an exponent, which is determined from the slope of log(I_{PH})-log(L) plot.

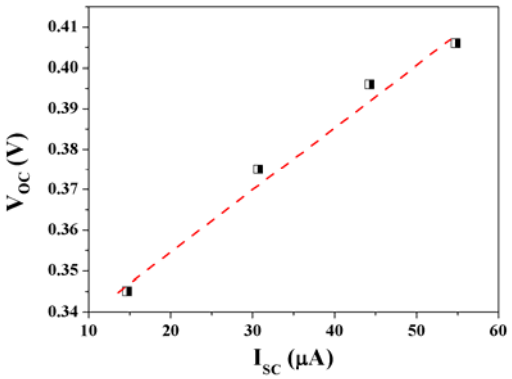

Figure 4. Illumination dependent V_{oc} vs. I_{sc} plot of heterojunction based on BTB

The double logarithmic I_{PH} - L plot of heterojunction based on BTB is given in Figure 5 to investigate the photo sensing property of the heterojunction. The value of α obtained from the measurement was determined as 0.614, which corresponds to the presence of continues distribution of localized trap levels [16]. The obtained value of α (0.614) for the related structure is higher than that of reported as 0.49, 0.52, and 0.57 in the reference [16], [1] and [6], respectively. It can be stated that Al/BTB/p-Si structure can be better photo sensing property than those of devices in the literature [1,6,16]. Hence, it can be said that the structure can be suitable for the photodiode and the photo sensor application.

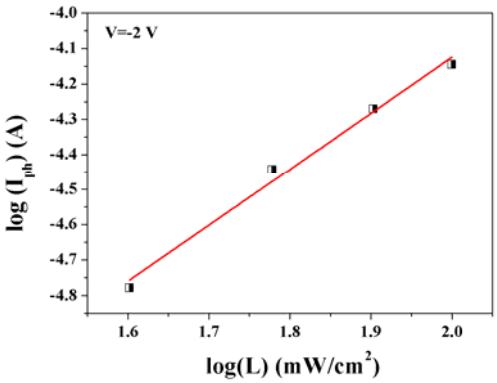

Figure 5. Logarithmic photocurrent vs illumination intensity plots of heterojunction based on BTB

For further assessment about the photo responsivity of fabricated heterojunction about with various light powers, the relation can be expressed [17];

$$R=I_{PH}/L.S \quad (2)$$

where, *S* is the illuminated area. The estimated values of *R* were given in Table 2. As seen in the table, these values are exponentially dependent on the illumination power. This confirms that the enhancement in the responsivity of the heterojunction with the illumination power is resulted in the generated free carriers by the absorption of the incident photons' energy. As seen from the Table 2, the values of responsivity for the studied heterojunction based on BTB are higher than that of device reported in the ref. [16]. According to the results of the heterojunction, it can be possible to use the innovative fabrication process for the improvement of the photovoltaic parameters in solar cells, and dye sensitized solar cell devices.

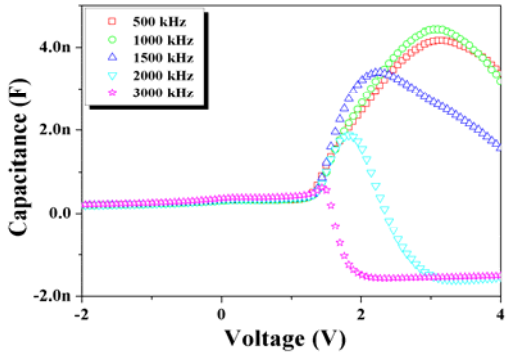

Figure 6. The frequency dependent C-V plots of heterojunction based on BTB

Another important analysis is capacitance (C-V) measurement at high and low frequencies to characterize of device. The capacitance of heterojunction concerns about the diffusion capacitance and depletion capacitance. The frequency dependent *C-V* plots of heterojunction are presented in Figure 6. As seen in the figure, the capacitance of studied structure changed with both the applied voltage and frequency. The value of capacitance is very close to each other at reverse bias regime under various frequencies. For the forward bias region, there is a peak related to the interface states. The maximum value of that peak decreases with the increasing in frequency. Because, at sufficiently high frequency, these charges have not enough sensitive to the a.c. signal, resulted in the decrease at the capacitance value [8]. Moreover, negative behaviour of capacitance, called negative capacitance was observed in forward bias at high frequencies. This can be ascribed to the loss of interface states charges at the interface because of the impact ionization process. Similar results on negative capacitance phenomenon have been reported for the Al/rhodamine-101/n-GaAs Schottky barrier diodes by Vural et al. [20]. Thus, the interface states charges have mainly importance on the capacitive property of the diode.

The effect of the applied frequency on the resistance (R_s), which is the real part of impedance, as a function of bias voltage was experimentally studied for the heterojunction based on BTB, and as seen from the Figure 7. The figure shows that the value of the resistance is almost constant at reverse bias, on the other hand there is a peak located in forward bias regime, and the max point of the peaks decrease when the frequency increases. In addition, the peak position of the curves moves towards to higher voltage region with the frequency. This means that, the resistance is affected by the applied frequency, which is caused by the dependency of the interface states charges on frequency. At low frequencies, these charges can follow the a. c. signal, and an excess capacity can be formed, that is resulted in the high value of resistance [16,17].

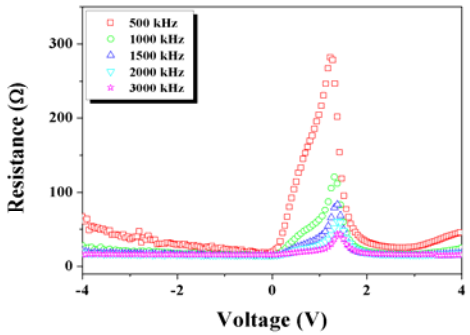

Figure 7. The frequency dependent R_S-V plots of heterojunction based on BTB

4. Conclusion

In this research, BTB thin film was deposited in between the metal and the p type semiconductor as an interfacial layer by spin coating technique. The effect of the illumination power on the photovoltaic parameters of fabricated device was investigated with different incident light flux. The value of both the generated current by photon and the corresponded voltage of device enhances with the increasing in the illumination power. Also, the value of the photo responsivity enhances with the illumination power. The relation between short circuit current and incident light power suggest continuous distribution of localised interface states for the studied device. The obtained results confirm that the photoconductivity of device was promoted by the interfacial layer due to increasing in the number of the generated free carriers. It is good candidate for optoelectronic device application such as the optical sensor and photo diode to optimize the photovoltaic parameters owing to its property of the higher photo sensitivity and the photo responsivity. The frequency dependent characteristic of capacitance is explained by the frequency dependent characteristic of interface states charges. The obtained results confirm that the photovoltaic parameters of the device were drastically affected by the incident light power. It can be also possible the controlling these parameters by the organic thin film layer, and improvement of the device performance.

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References

[1] Gencer Imer, A., Ocak, Y. S. 2016. Effect of light intensity and temperature on the current voltage characteristic of Al/SY/p-Si organic-inorganıc heterojunction. Journal of Electronic Materials 45(2016) 5347-5355

[2] Gencer Imer, A., Tombak, A., Korkut, A. 2016. Electrical and photoelectrical characteristic investigation of new generation photodiode based on bromothymol blue dye. Journal of Physics: Conference Series, 707(2016), 012012.

[3] Tombak, A., Ocak, Y. S., Asubay, S., Kilicoglu, T. Ozkahraman, F. 2014. Fabrication and electrical properties of an organic–inorganic device based on Coumarin 30 dye. Mater. Sci. Semi. Proc. 24(2014) 187-192.

[4] Farag, A. A. M., Mansour, A. M., Ammar, A. H., Abdel Rafea, M. 2011. Characterization of electrical and optical absorption of organic based methyl orange for photovoltaic application. Synthetic Metals, 161(2011), 2135-2143

[5] Yakuphanoglu, F., Ocak, Y. S., Kılıcoglu, T., Farooq, W.A. 2011. Interface control and photovoltaic properties of n-type silicon/metal junction by organic dye. Microelectron. Eng. 88(2011), 2951-2954.

[6] Phan, D. T., Gupta, R. K., Chung, G. S., Al-Ghamdi, A. A., Al-Hartomy, O. A., El-Tantawy, F., Yakuphanoglu. 2012. Photodiodes based on graphene oxide–silicon junctions. Solar Energy, 86(2012), 2961-2966.

[7] Ugur, A., Gencer Imer, A., Ocak, Y. S. 2015. Electrical and photoelectrical characterization of an organic–inorganic heterojunction based on quinoline yellow dye. Mater. Sci. Semic. Proc., 39(2014), 569-574.

[8] Tascıoglu, I., Farooq, W. A., Turan, R., Altındal, S., Yakuphanoglu, F. 2014. Charge transport mechanisms and density of interface traps in MnZnO/p-Si diodes. J. Alloy Compd., 590(2014) 157–161.

[9] Soylu, M., Al-Hartomy, O. A, Al-Said, S. A. F., Al-Ghamdi, A. A., Yahia, I.S., Yakuphanoglu, F. 2013. Controlling of conduction mechanism and electronic parameters of silicon-metal junction by mixed methylene blue/2'-7'-diclorofluorescein. Microelectronics Reliability, 53(2013), 1901-1906.

[10] Gencer Imer, A., Temirci, C., Gulcan, M., Sonmez, M. 2014. Electrical characteristics of organic/inorganic Pt (II) complex/p-Si semiconductor contacts. Mater. Sci. Semic. Proc., 28(2014), 31-36.

[11] Aydoğan, Ş., Güllü, O. 2010. A study of the rectifier behavior of aniline green based Schottky diode. Microelectronic Engineering, 87(2010), 187-191.

[12] Bilkan, Ç., Zeyrek, S., San, S.E., Alındal, Ş. 2015. A compare of electrical characteristics in Al/p-Si (MS) and Al/$C_{20}H_{12}$/p-Si (MPS) type diodes using current–voltage (*I–V*) and capacitance–voltage (*C–V*) measurements. Mater. Sci. Semi. Proc. 32(2015) 137-144.

[13] Çaldıran, Z., Deniz, A. R., Coşkun, M.F., Aydoğan, Ş., Yeşildağ, A. Ekinci, D. 2014. I–V–T (current–voltage–temperature) characteristics of the Au/Anthraquinone/p-Si/Al junction device. Journal of Alloys and Compounds, 584(2014), 652-657

[14] Yahia, I. S., Shakra, A. M., Fadel, M., Hafez, H. S., Micheal, M. M., Yakuphanoglu, F. 2014. Photovoltaic response of dye-sensitized solar cell using 2′,7′-dichlorofluorescein as an organic dye Mater. Sci. Semi. Proc. 28 (2014) 77-83.

[15] Kazim, S., Ali, V., Zulfequar, M., Hak, M. M., Husain, M. 2013. Electrical transport properties of poly[2-methoxy-5-(2′-ethyl hexyloxy)-1,4-phenylene vinylene] thin films doped with acridine orange dye. Physica B, 393(2013), 310-315.

[16] Soylu, M., Cavas, M., Al-Ghamdi, A. A., Gafer, Z. H., El-Tantawy, F., Yakuphanoglu, F. 2014. Photoelectrical characterization of a new generation diode having $GaFeO_3$ interlayer. Sol. Ener. Mater. Sol. Cells 124(2014) 180-185.

[17] Tecimer, H., Türüt, A., Uslu, A., Uslu, I. 2013. Temperature dependent current-transport mechanism in Au/(Zn-doped)PVA/n-GaAs Schottky barrier diodes. Sens. Actuators A 199(2013), 194-201.

[18] Gullu, O., Kilicoglu, T., Türüt, A. 2010. Electronic properties of the metal/organic interlayer/ inorganic semiconductor sandwich device. J. Phys. Chem. Solids, 71(2010) 351–356.

[19] Kılıçoglu, T., Tombak, A., Ocak, Y.S., Aydemir, M. 2014. Electrical and photoelectrical characterization of a TTF/p-InP organic–inorganic heterojunction. Microelectron. Eng., 129(2014), 91-95.

[20] Vural, O., Safak, Y., Turut, A., Altındal, A. 2012. Temperature dependent negative capacitance behavior of Al/rhodamine-101/n-GaAs Schotthy barrier diodes and Rs effects on C-V and G/w-V characteristics. J. Alloys Compd., 513(2012) 107-111.