

Electrical and photovoltaic properties of Al/p-Si structures with PTCDA interlayer in darkness and daylight

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This article summarizes the changes in the electrical and photovoltaic characteristics of the Al/p-Si structures with PTCDA interlayer under darkness and daylight. The values of basic electrical characteristics such as ideality factor (n), barrier height (Φ_{bo}), rectification ratio (RR) and saturation current (I_0) obtained from current-voltage (I - V) measurements at room temperature (300 K). Furthermore, the photovoltaic characteristics such as open circuit voltage (V_{oc}), short circuit current (I_{sc}), fill factor (FF), and maximum power (P) **were acquired** as 0.09 V, 4.85×10^{-8} A, 0.427 or 42.7 %, 1.86×10^{-9} W under daylight light intensity, respectively. The experimental results show that the Al/PTCDA/p-type Si semiconductor structure shows photovoltaic behavior even in daylight. The experimental results suggests that Al/PTCDA/p-type Si semiconductor structure can increase efficiency in electronic devices, and also can be employed as a photodiode.

Keywords: PTCDA, p-Si, Electrical properties, Photovoltaic parameters

Submission Date: 04 August 2023

Acceptance Date: 01 September 2023

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1. Introduction

Today, as energy consumption increases due to population growth, the need for alternative energy sources or renewable energy sources is increasing day by day. Renewable energy source means that it can renew itself at a rate equal to the energy taken from the energy source or faster than the rate of depletion of the source. For this reason, people have become more dependent on electronic devices, which are considered the basis of energy. Because solar energy is considered the most important alternative energy source in this context, as it offers almost all the necessary features. Thus, photovoltaic devices make it possible to benefit from electrical energy by converting sunlight into energy because their electrical properties change according to the amount of light they are exposed to. Therefore, we need to use sustainable energy sources to meet the energy needs of future generations and to reduce the waste to the environment. These developments are extremely important.

Also, this means that photovoltaic technologies can make significant contributions to energy needs. Because the most important problem for the development of a country is energy. Si semiconductor structures are the most used devices in electrical and electronic circuit elements. Metal semiconductor (MS) or metal oxide semiconductor (MOS) structures have low voltages and high switching actions. For this reason, it is important to investigate the effects of light on electronic circuit elements in different environments and look at their distinctive qualities. Because the presence of any thin layer between the metal and semiconductors can cause interfacial charge due to the electric field formed at the interface, and therefore the electrical properties of semiconductor devices can change under light intensity [1-8]. In this study, we used perylenetetracarboxylic dianhydride (PTCDA) semiconductor thin layer as the interface layer. In other words, we used an organic semiconductor such as PTCDA at the interface instead of the

naturally occurring thin oxide layer between the metal and the Si semiconductor. Our main aim in this study is to examine the electrical and photovoltaic properties of Al/PTCDA/p type Si structure in dark and daylight (room light). Thus, the barrier height, ideality factor and series resistance values of the Al/TCDA/p-type Si structure in the dark and daylight were obtained using current-voltage (I - V) measurements. Additionally, for Al/TCDA/p-type Si structure, photovoltaic characteristics such as open circuit voltage (V_{oc}), short circuit current (I_{sc}), fill factor (FF), and maximum power (P) calculated in daylight intensity. It was seen that the electrical properties of the Al/PTCDA/p-Si structure changed in daylight and there was an increase in the charge transitions due to the decrease in the ideality factor. This is means that he Al/PTCDA/p-Si structure is very sensitive to light. Thus, experimental studies showed that Al/PTCDA/p-Si structures have good photovoltaic properties for solar cells even in normal light (daylight).

2. Methods and Materials

In this study, Si and PTCDA semiconductor materials used were purchased. Firstly, the wafer cleaned using the RCA1 cleaning process to remove contaminants from the semiconductor surfaces [9]. To make ohmic contacts, Al metal (99.999 percent) was evaporated at roughly 10^{-6} Torr in a thermal evaporation system. After, the solution of (GO:PTCDA) thin organic layer, 1:1 solution (10^{-3} mol L $^{-1}$), were prepared in chloroform. The semiconductor wafer front faces were coated (GO:PTCDA) (1:1) solutions with spin speed of 1000 rpm for 30 s by spin coating method (6800 Spin Coater Series). Following these procedures, to make a rectifier Al metal contact with diameter of 1 mm (rectifier contact area= 7.85×10^{-3} cm 2) at 10^6 Torr pressure Al (% 99.999) metal was thermally evaporated on the surface of organic layer-semiconductor pieces. The I - V measurements of the Al/PTCDA/p-Si structure in the dark and in daylight were made using a Keithley 2400 Source-Meter at room temperature. The general diagram of the Al/PTCDA/p-type semiconductor structure was obtained as shown in Fig. 1.

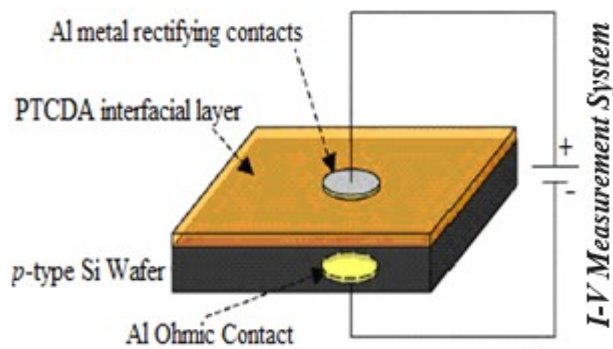


Fig.1. The general diagram of Al/PTCDA/p- structure

3. Results and Discussions

3.1 Electrical properties of the Al/PTCDA/p-Si structure

Figure 2 shows the $\ln(I)$ - V curves of the Al/PTCDA/p-Si structure under darkness and daylight in the range of ± 3.0 V. As seen in Figure 2, the Al/PTCDA/p-Si/Al structure shows a rectifying feature at low voltages in the forward bias region both in the dark and in daylight. The correlation between I and V can be written as follows according to thermionic emission (TE) theory [5-8]:

$$I = I_0 \exp\left(\frac{q(V - IR_s)}{nkT}\right) \left[1 - \exp\left(\frac{-q(V - IR_s)}{kT}\right)\right] \quad (1)$$

Here, q , V , n , k , and T constants is electronic charge value, voltage, ideality factor, Boltzmann constant and temperature, respectively. Also, I_0 is the saturation current density, and can be written as follows;

$$I_0 = AA^* T^2 \exp\left(-\frac{q\Phi_{bo}}{kT}\right) \quad (2)$$

If here, A , A^* and Φ_{bo} are contact are of diode, Richardson constant, and barrier height, respectively.

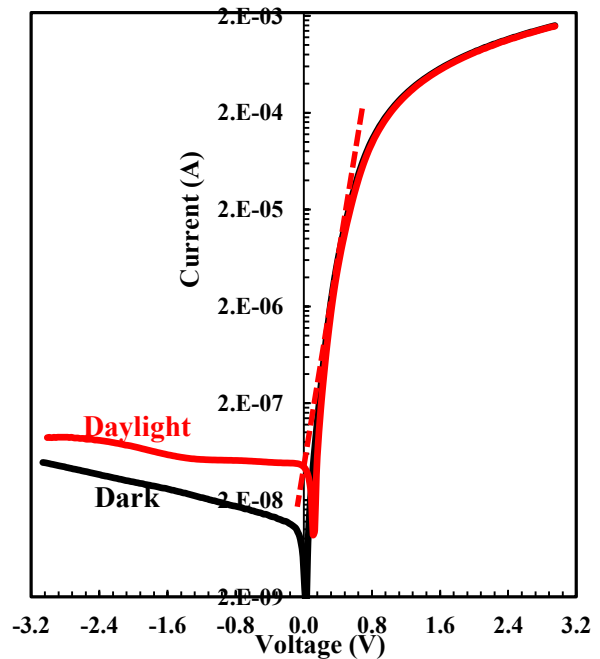


Fig.2. The I - V curves of Al/PTCDA/p-Si/Al structure in dark and daylight

From Eqs. (1) and (2), n and Φ_b equations is written as follows [1-8]:

$$n = \frac{q}{kT} \left(\frac{dV}{d \ln I} \right) \quad (3)$$

and

$$\Phi_{bo} = \frac{kT}{q} \ln\left(\frac{AA^* T^2}{I_0}\right) \quad (4)$$

According to Eqs. (3) and (4), values of n and Φ_{bo} of the Al/PTCDA/p-Si device obtained to be 2.857-2798 and 0.7078-07104 eV in dark and daylight, and these values shown also Fig. 3 and Table 1.

Table 1. The electrical values of the Al/PTCDA/p-Si device

Al/PTCDA/p-Si	n	$\Phi_{bo}(eV)$	$I_0 (10^{-8} A)$	$R_S(\Omega)$
Dark	2.857	0.7078	2.98	2497.58
Daylight	2.798	0.7104	2.70	3125.00

Additionally, the rectification ratio values were obtained from formula at $RR=R_{forward\ current}/R_{reverse\ current}$. The RR values of the Al/PTCDA/p-Si structure in dark and daylight are $1.02 \times 10^4 - 3.78 \times 10^3$ at ± 1.0 V; $2.74 \times 10^4 - 1.19 \times 10^4$ at ± 2.0 V; $3.24 \times 10^4 - 1.71 \times 10^4$ were obtained at ± 3.0 V, and these values shown also Fig. 4, respectively.

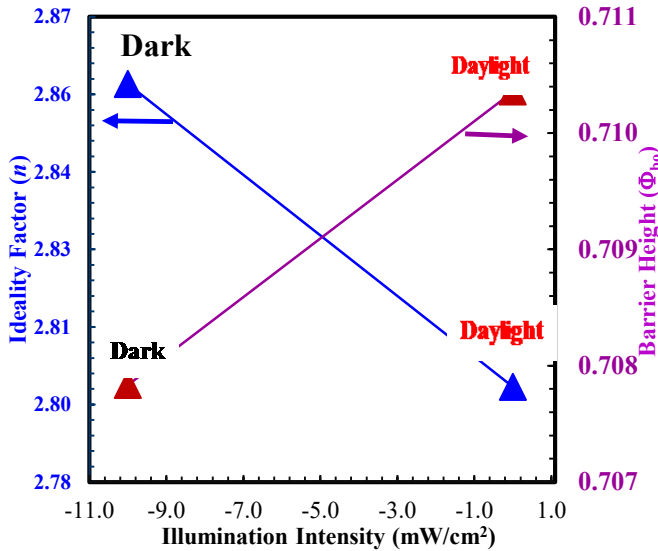


Fig. 3. The n and Φ_{bo} changes in dark and daylight

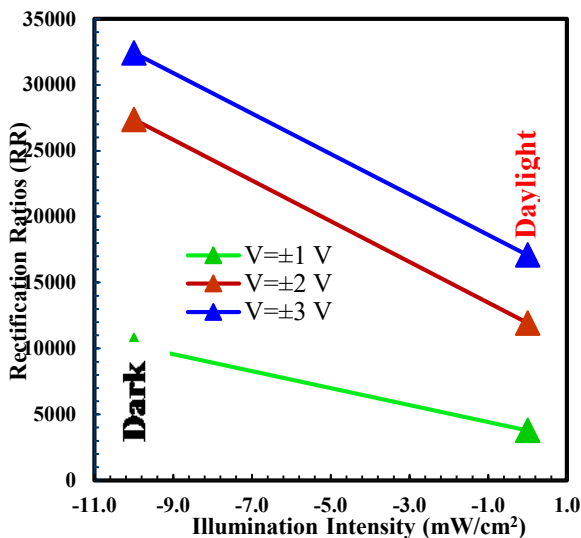


Fig. 4. The RR values of the Al/PTCDA/p-Si structure

As can be seen, the values of ideality factors and rectification ratio obtained in the dark are higher than the values obtained in daylight. Likewise, the values of barrier height obtained in the dark are lower than the values obtained in daylight. This means that conductivity or charge mobility increases depending on light. Also, it also shows that the Al/PTCDA/p-Si structure is a good rectifier and photovoltaic structure.

Additionally, series resistance (R_S) is a fundamental property to describe semiconductor structures. In this study, we calculated series resistance values with the Norde [10] method. Norde's function can be written as follows:

$$F(V, \gamma) = \frac{V}{\gamma} - \frac{kT}{q} \ln\left(\frac{I(V)}{AA^*T^2}\right) \quad (5)$$

$$\Phi_b = F(V_0) + \frac{V_0}{\gamma} - \frac{kT}{q} \quad (6)$$

$$R_S = \frac{\gamma - n}{I} \frac{kT}{q} \quad (7)$$

From Eqs. 5, 6, and 7, γ is any constant slightly larger than the n values obtained from Fig.2, the Φ_b and R_S are the values obtained according to the Norde's function, $F(V_0)$ is the minimum point of the $F(V)-V$ plots, V_0 and I are the voltage and current values, respectively. Fig. 5 shows $F(V)-V$ plot of the Al/PTCDA/p-Si structures under dark and at daylight.

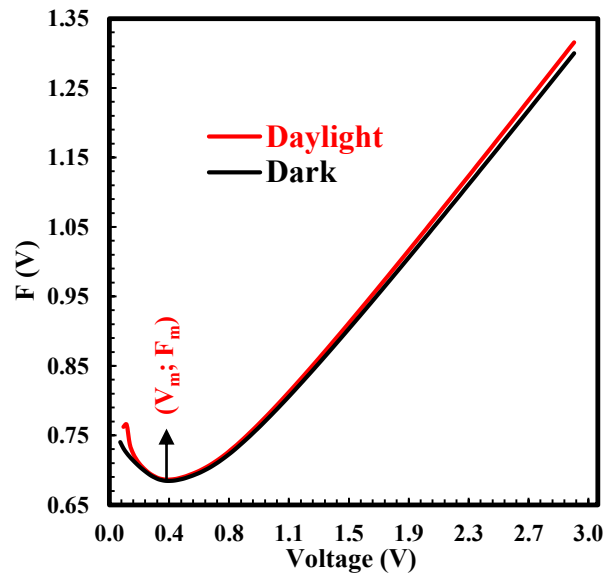


Fig. 5. $F(V)-V$ plots the Al/PTCDA/p-Si structure in dark and daylight

According to Eqs. 5, 6, and 7, the Φ_b and R_S values of the Al/PTCDA/p-Si structure were obtained as 0.7693-0.7723 eV; 2497.58-3125.00 Ω in dark and daylight, respectively. As can be seen, the barrier height values obtained from the Norde method are higher than the values obtained from the thermionic emission theory. This is due to method differences, and also because the Norde method takes into account values in the full forward bias region.

3.1 Photovoltaic properties of the Al/PTCDA/p-Si structure

The values of photovoltaic parameters of the Al/PTCDA/p-Si structure were determined from I-V measurements. The photovoltaic characteristics of the Al/PTCDA/p-type Si structure in daylight at room temperature shown in Fig. 6.

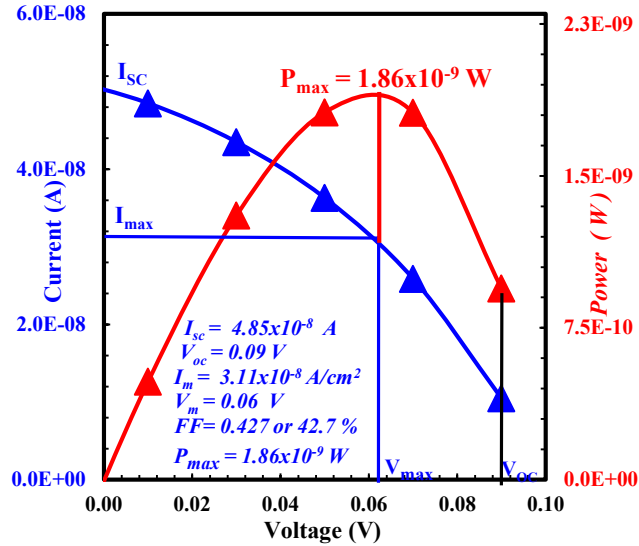


Fig. 6. The I-V and P-V curves of the Al/PTCDA/p-type Si structure in daylight.

As can be seen in Fig. 6, the photovoltaic values of the Al/PTCDA/p-Si structure such as open circuit voltage (V_{oc}), short circuit current (I_{sc}), fill factor (FF), and maximum power (P_{max}) were acquired as 0.09 V, 4.85×10^{-8} A, 0.427 or 42.7 %, 1.86×10^{-9} W under daylight light intensity, respectively. Here, the value of fill factor can be obtained from the equation given below [11-13];

$$FF = \frac{I_m V_m}{I_{sc} V_{oc}} \quad (8)$$

Filling factor (FF) is an important parameter used to determine the efficiency of photovoltaic device. As can be seen in Eq. 8, the fill factor is obtained by dividing the maximum power output by the actual power output. Thus, this value gives us the performance of our photovoltaic device.

4. Conclusion

In this study, the electrical and photovoltaic properties of the Al/PTCDA/p-Si structure were investigated using I-V measurements under dark and in daylight. It was seen that the electrical properties of the Al/PTCDA/p-Si structure changed in daylight and there was an increase in the charge transitions due to the decrease in the ideality factor. This is also means that the Al/PTCDA/p-Si structure is very sensitive to light. Furthermore, we can say that the Al/p-Si structure shows a photovoltaic feature even in daylight. As

conclusion; the experimental results suggested that Al/PTCDA/p-Si structure may be employed as a photodiode in electronic and optoelectronic devices.

Acknowledgement:

This work was supported by Kahramanmaraş Sütçü İmam University Scientific Research Project Unit (Project number: 2023/4-7 M). We would like to thank Kahramanmaraş Sütçü İmam University for financial support of the research program.

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