



Determining the Efficiency of Prepared Thin-Film Organic/Si Solar Cell

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Abstract

A film of DBM is deposited on a -Si single crystal to fabricate a p-DBM/n-Si (thickness ≈ 90 nm). Researchers have explored the electrical and photoelectrical characteristics of photovoltaic cells **by analyzing current. have been studied through current analysis. Photovoltaic cell.** Electrical and photoelectrical properties have "The matter has been under investigation." by the current density – voltage measurements at different temperatures ((J-V) characteristics)."The fabricated cell displayed rectifying properties, with a rectification ratio." $R=4043$ at 1 Volt. The obtained value of the series resistance R_s and the shunt resistance R_{sh} at room temperature were determined to be 750Ω and 1700Ω , respectively. At low voltages ($V < 1V$), the dark forward current density is controlled by the tunneling mechanism, while at relatively high voltage ($V > 1V$), a space charge-limited-conduction mechanism is observed, controlled by a single trap level. The C-V measurements indicate an abrupt junction with a built-in voltage of 0.78V. Finally, the cell exhibited photovoltaic characteristics with an open-circuit voltage of 780 mV, a short-circuit current of 1.2×10^{-6} mA, and a power conversion efficiency of 1.48%. These parameters were estimated at room temperature under light illumination from a source with an input power density of 20 mWatt/cm². These parameters were estimated at room temperature under light illumination from a source with an input power density of 20 mWatt/cm².

Key Words:

Thin-film, Heterojunction, Efficiency, Solar cell.

1. Introduction:

Energy from the sun is converted into electrical energy by devices with organic solar cells. In order to produce the most electricity possible while exposed to sunlight, semiconductor diodes are used to create solar cells. Because of variations in temperature, optical excitation, and impurity content, semiconductors have electrical

conductivities that range from those of metals to insulators. Two different semiconductor kinds make up a p-n junction: p-type and n-type. An intersection of a positively doped (p-type) and a negatively doped (n-type) semiconductor results in a p-n junction. Carrier drift is encouraged and additional carrier diffusion is inhibited by the space charge area and electric field established by this connection.

The equilibrium state is attained when the carriers diffusion and drift currents cancel one another out. Whether the electrode creates an ohmic or blocking contact for charge carriers depends on the choice of materials used to form the interaction with the semiconductor. Al, Ca, In, and Ag are frequently used as electrode materials in organic solar cells for collecting electrons, while Au is used for collecting holes. In solar cells and LEDs, at least one contact must be transparent. Semi-transparent materials, such as sublimed metals, can help achieve this. [1]

The conjugated solids that make up organic photovoltaic materials are principally affected by partially delocalized π and π^* orbitals in terms of both light absorption and charge transport. Materials that are appropriate for use in photovoltaic applications include crystalline or polycrystalline films made up of "small molecules" (molecules weighing a few hundred) as well as amorphous films made up of small molecules that are deposited by vacuum deposition or solution processing. Combinations of these substances with inorganic or additional organic solids are also feasible alternatives.

There are many distinctions between organic and inorganic solids. For example, in organic materials, carrier production frequently requires about 100 meV and does not always result from light absorption alone. Rather than band transport, charge transfer in organic solids usually entails hopping between localized states, which leads to reduced mobilities. These properties result from the bonds in organic solids having intermolecular Van der Waals forces that are substantially less than those in inorganic crystals.

In addition, compared to the sun spectrum, the spectral range of optical absorption in organic materials is somewhat small. Organic materials frequently have high absorption coefficients ($\sim 10^5 \text{ cm}^{-1}$), which allows for the attainment of high

optical densities at peak wavelengths in films thinner than 100 nm. Furthermore, the presence of oxygen or water can cause a lot of organic molecules to degrade. In the presence of water or oxygen, many materials become unstable. They can have extremely anisotropic electrical and optical properties since they are one-dimensional semiconductors. For the design of devices, this could be helpful. Many organic solids have a high degree of disorganization, which exacerbates low mobility. Transitions from π to π^* are typically the optical excitations that visible photons can reach.

Organic photovoltaic devices are limited by various attributes. To break apart the photosynthesized exactions, a strong driving force needs to exist. The photocurrent in the solar spectrum is limited by low charge carrier mobilities and limited light absorption. Defective interfaces on gadgets can have serious consequences. Since hopping transfer occurs, the photocurrent is temperature-sensitive [2].

The process of an electron moving from the highest occupied molecular orbital (HOMO) to the lowest unoccupied molecular orbital (LUMO) in a photovoltaic (PV) device to produce an exciton occurs after light absorption. After then, there is exciton dissociation, which leads to the electron and hole moving in different directions toward different electrodes.

The synthesis of thin films of Ch-diisoQ was studied by A. Darwish et al. They described a method of fabricating these films using the thermal evaporation technique, which is a commonly used technique for depositing thin films of various materials. In order to create a thin film, this method entails heating the Ch-diisoQ material until it evaporates, then letting the vapor condense onto a substrate. Using infrared spectroscopy, which provides information on the functional groups in the molecule and facilitates structural determination, the molecular structure of Ch-

diisoQ was examined in both its powder and as-deposited/annealed thin-film forms.

Ch-diisoQ thin films were found to have a nanostructure using X-ray diffraction (XRD) research. A higher annealing temperature resulted in a larger crystal size for the material. The crystalline structure of Ch-diisoQ thin films appears to be influenced by annealing. Ch-diisoQ thin-film dark electrical conductivity was investigated at both as-deposited and annealed temperatures between 298 and 423 K. Growing annealing temperature resulted in a decrease in activation energy, which controls the temperature dependence of conductivity.

At low voltages, the conduction mechanism in Ch-diisoQ thin films was found to be Ohmic, suggesting linear current-voltage characteristics. However, at high voltages, the conduction mechanism transitioned to space charge limited conductivity (SCLC), indicating the presence of localized traps that influence charge transport. Fundamental electronic properties such as the Fermi level position (EF), electron mobility (μ), and concentration of traps (Nt) were calculated. The calculated values ($E_F = 0.231$ eV, $\mu = 1.56 \times 10^{-10}$ cm² V⁻¹ s⁻¹, $N_t = 3.35 \times 10^{14}$ cm⁻³) indicate the potential of Ch-diisoQ thin films for applications in heterojunction solar cells. The values suggest efficient charge transport and low trap densities, which are desirable for solar cell performance.

These results improve the understanding and refinement of Ch-diisoQ thin films for use in renewable energy technologies[3]. The study provides important insights into the structural, electrical, and electronic characteristics of Ch-diisoQ thin films, highlighting their suitability for applications in photovoltaic devices like heterojunction solar cells[3].

Thermally evaporated 5,10,15,20-tetraphenyl-21H, 23H-porphine iron (III) chloride FeTPPCl

and p-type Si wafer were used by M. El-Nahass et al. to build a heterojunction. Both thermally triggered carrier recombination and rectification behavior were seen at the junction. With a drop in temperature, barrier heights reduced and ideality factors increased. 2.8 mA short-circuit current, 0.475V open-circuit voltage, and a 32% fill factor were noted under light[4].

An Al/NTCDA/p-Si/Al device was examined at various temperatures by Ahmed Nawar et al. With rising temperatures, the idealism factor dropped and the barrier height increased. It was discovered that the barrier height had a mean of 1.5 eV and a standard variation of 20 mV. The series resistance dropped as the temperature rose. A passivation process can be used to illustrate how the distribution of interface states was affected by inserting NTCDA between the electrode and p-Si [5].

S. Al Garni et al. used the thermal evaporation method to create hybrid organic-inorganic solar cells. With a rectification ratio of 157 at ± 1 V, the cell exhibited rectifying action. At lower voltages, the dark current density was governed by the thermionic emission instrument, and at higher voltages, by a space charge-limited-conduction process. Adding an InSe layer to the cell resulted in a roughly nine-fold increase in conversion efficiency, as well as a notable improvement in the short circuit photocurrent density and fill factor. It was discovered that temperature increased the power conversion efficiency [6].

Using standard thermal evaporation methods, M. El-Nahass et al. created an n-SO/P-Si heterojunction by depositing a thin layer of 1,3,3-Trimethylindolino- β -naphthopyrrolospiran (SO) onto a P-Si single crystal substrate. At low voltage, forward conduction was mostly controlled by thermoionic emission, whereas at high voltage, space-charge-limited current (SCLC) processes were dominant. When the device was

continuously illuminated at room temperature with 5 mW/cm^2 , it demonstrated noticeable photovoltaic characteristics. [7]

N. Khusayfan et al. presented the results of heterojunction indigo thin films on silicon that were created utilizing the thermal evaporation method in a high vacuum. It was discovered that, at low voltage, thermionic emission dominated the charge transport mechanism in this indigo on silicon, and that, at higher voltages, single trap distribution dominated space charge limited conduction SCLC. It was discovered that p-Si was the main source of the reverse current at reverse applied voltage because of generation-recombination. These devices' capacitance-voltage (C-V) properties were evaluated at a high frequency of 1 MHz. Under white illumination, the I-V characteristic parameter was computed. [8]

Through the use of vacuum thermal evaporation, Saleem Qashou et al.'s study produced thin films of Au/Ch-diisoQ/p-Si/Au. On a p-Si substrate, an organic substance called Ch-diisoQ was deposited. Deposition parameters must be precisely controlled during this process. to achieve the desired levels of homogeneity and film thickness. They employed atomic force microscopy (AFM) and X-ray diffraction (XRD) patterns to examine the morphology and structure of the Ch-diisoQ layer. AFM delivers insights into surface shape at the nanoscale, whereas XRD provides information regarding crystal structure.

The parameters of dark current density-voltage were examined across a range of temperatures. The presence of space charge limited current at high forward bias voltage and thermionic emission at low voltage indicates distinct conduction mechanisms under various circumstances. In order to better understand how temperature influences device performance, they examined the temperature dependency of reverse current density utilizing Poole-Frenkel and Schottky's effects [9].

In an investigation conducted by H. Zeyadaa et al., scientists created a hybrid hetero junction solar cell by utilizing a thermal evaporation method to deposit an indium phthalocyanine chloride derivative (InPcCl-D) onto a p-type silicon single crystal wafer. To achieve the intended device features, this material and deposition technique selection is essential. Current-voltage and capacitance-voltage measurements, which offer comprehensive details about the electrical behavior of the device, were used to characterize the manufactured cell. The examination of dark current-voltage characteristics at varying temperatures provides valuable information on the predominant conduction processes and how they vary with temperature. Understanding how temperature impacts device performance and behavior is made possible by the estimation of junction parameters as functions of temperature [10].

In a work by H. Zeyadaa et al., the thermal evaporation method is used to deposit films of two distinct quinoline derivatives onto p-Si substrates. Device features and performance are probably impacted by material selection. grasp device operation requires a grasp of the optical and electronic properties of the quinoline derivatives, which can be obtained by illustrating their absorbance and energy band diagrams.

Understanding the behavior of heterojunction diodes under various conditions can be achieved by examining their electrical properties through the examination of current-voltage characteristics. The relative benefits and downsides of each material system can be understood by comparing devices made of different materials [11].

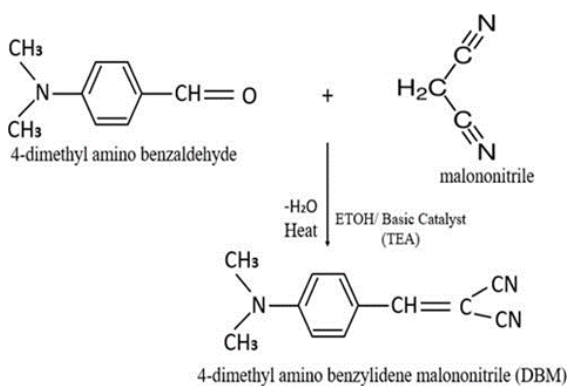
Each study contributes to the understanding and advancement of hybrid heterojunctions for solar cell applications through meticulous fabrication, comprehensive characterization, and performance evaluation. By analyzing each aspect in detail,

researchers can identify opportunities for optimization and further improvement in device performance.

2. Methods of Research and the tools used

The experimental techniques used in this research focus on the structural, optical, electrical, and photovoltaic properties of thermally evaporated 4-dimethyl amino benzylidene malononitrile (DBM) thin films. The structural properties were analyzed by employing Analyses involving X-ray diffraction (XRD), scanning electron microscopy (SEM), and Fourier transform infrared spectroscopy (FTIR).

Optical properties were examined through spectrophotometric measurements of transmittance and reflectance at normal incidence. Electrical properties were investigated using conductivity measurements, employing the two-probe method. The photovoltaic properties of DBM/n-Si heterojunctions were evaluated through current density-voltage (J-V) and capacitance-voltage (C-V) measurements.



The DBM used in the study was prepared through a chemical reaction between 4-dimethyl amino benzaldehyde and malononitrile in ethanol. The reactants were dissolved in ethanol, and triethylamine (TEA) was added as a catalyst. After heating for 30 min and After reaching room temperature, a precipitate developed, which was subsequently filtered and rinsed with ethanol. The resultant product was dissolved in ethanol, filtered once more, and underwent crystallization, leading to the emergence of yellow needle-shaped crystals.

The preparation of DBM thin films involves

depositing them via thermal evaporation on different substrates selected based on the specific properties being studied. Glass substrates are used to examine structural and electrical properties, quartz substrates for optical properties, and potassium bromide (KBr) single crystal substrates for IR measurements.

The cleanliness of the substrates is crucial for achieving high-quality films, as it significantly impacts the morphology and growth of the deposited films. To ensure proper cleaning, the substrate is immersed in a sodium hydroxide solution for a duration of 24 hours to eliminate grease, fingerprints, and small particles. It is then washed multiple times with distilled water and immersed in chromic acid for another 24 hours. Afterward, the substrate is washed with distilled water and then with ethyl alcohol. Finally, it is rinsed with distilled water and dried using dry air [12-14].

The process of preparing thin films is by using the thermal evaporation technique. It describes the setup of a high vacuum coating unit and the steps involved in substrate cleaning. The cleaned substrates are mounted in the unit, facing the evaporation molybdenum boat, and the vacuum chamber is pumped down to 10^{-5} Pa. The boat is loaded with the material for evaporation, and the current passing through it is increased to initiate evaporation. The vapor condenses on the substrates, forming a solid film of the desired thickness. The deposition rate is controlled using a quartz crystal thickness monitor, and the films are kept under vacuum to prevent oxidation upon exposure to air [15,16].

For the preparation and electrical measurement of DBM/n-Si heterojunctions, initially, n-type Si wafers are cleaned and etched before being coated with a 55 nm thick DBM thin film using the thermal evaporation method. The top electrode is deposited in a grid form using Au to allow for current collection without obstructing incident light. The bottom electrode is coated

with Ag as an ohmic electrode [17]. Annealing the junction at 373 K for two hours improves its performance by removing potential channels that may have formed during preparation. [14]

Electrical measurements of the space-charge-limited current (SCLC) are conducted using a high impedance electrometer, varying temperature from 298-423 K, and applying voltages in the range of 0-60 V. The (I-V) characteristics can be obtained by measuring the resulting current corresponding to a certain voltage value across the junction, using a suitable circuit for I-V measurement, as Figure 1.

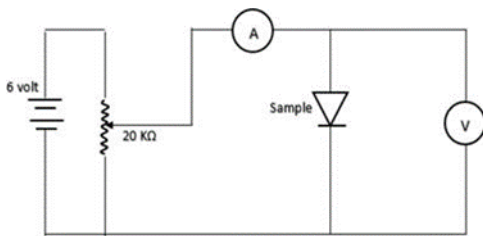


Figure 1.1. Electric circuit for measuring the I-V characteristic of p-n heterojunction.

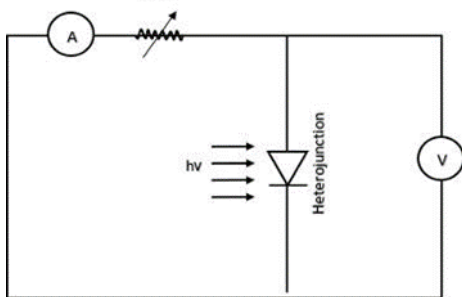


Figure 1.2. An electric circuit is used to measure the load I-V characteristic under illumination.

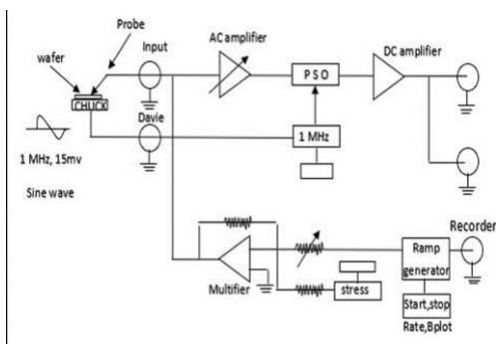


Figure 2 Simplified block diagram of model 1410 CV circuit

The process of measuring the capacitance-voltage (C-V) characteristic for the p- DBM/n-Si

heterojunction involved measurement conducted at room temperature using a computerized capacitance-voltage (C-V) system, which consists of a 410 C-V meter connected to a personal computer via a Model 4108 interface. The setup allows for the characterization of the heterojunction's electrical properties. [14]

3. Results of Research and discussions

Fig. 3 shows the dark current density–voltage characteristics, or the J–V characteristic, curves of the new DBM/n-Si cell at various temperatures, 303, 313, 323, 333, 343, 353, and 363 K. The diode-like behavior of the curves shows the formation of a barrier at the interface between the Si substrate and DBM film. It is also shown that, for a given applied voltage, the current increases as the temperature increases, which indicates that the conductivity has a positive temperature coefficient. The forward current divided by the reverse current (RR=JF/JR) is known as the rectification ratio (RR) ratio. It has been calculated at ±1V for a prepared cell and found to be 131 for the J-V measurements conducted at room temperature [18].

The dark forward current density can be fitted to the modified ideal diode equation [1]

$$J = J_{01} \left[\exp \frac{q(V - JR_s)}{n_1 k_B T} - 1 \right] + J_{02} \left[\exp \frac{q(V - JR_s)}{n_2 k_B T} \right] + \frac{V - JR_s}{R_{sh}}$$

Where J_0 stand for the reverse saturation current density, where n denotes the diode quality factor, q denotes the electronic charge, R_s denotes the series resistance, and R_{sh} is the shunt resistance.

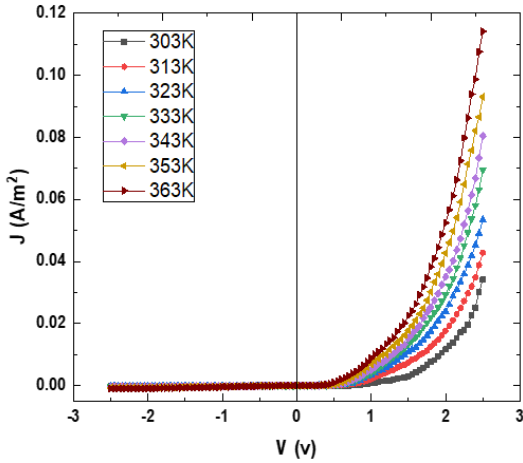


Figure 3 Dark J V characteristics of the fresh DBM/n Si cell at different temperatures in both forward and reverse bias

At a certain applied voltage (V_{con}), the rectification ratio, or RR, is the ratio of the forward current (I_F) to the reverse current (I_R). RR is shown as $(I_F/I_R) V_{con}$ in Figure 4. At +1 V, the RR value was found to be 4043.5. After measuring the cell, it was observed that its behavior demonstrated solid rectifying characteristics.

R_s "The series resistance" is the combination of the material's resistance and contact in the junction. Using Fig.4, the shunt resistance R_{sh} , represents the resistance from the leaking current through the junction. Where $R_j = \Delta V/\Delta I$, this can be found from the current-voltage curves. The junction resistance reaches a constant value at a high enough forward bias; this value is the series resistance or R_s . Conversely, at high enough reverse bias, the junction resistance remains constant and is equivalent to the diode shunt resistance R_{sh} . On the other hand, shunt resistances and junction series are crucial for enhancing cell design and performance. At room temperature, the series resistance (R_s) and shunt

resistance (R_{sh}) were found to be 750 Ω and 1700 Ω , respectively.

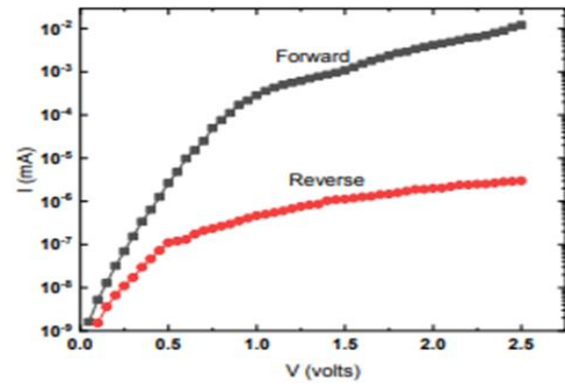
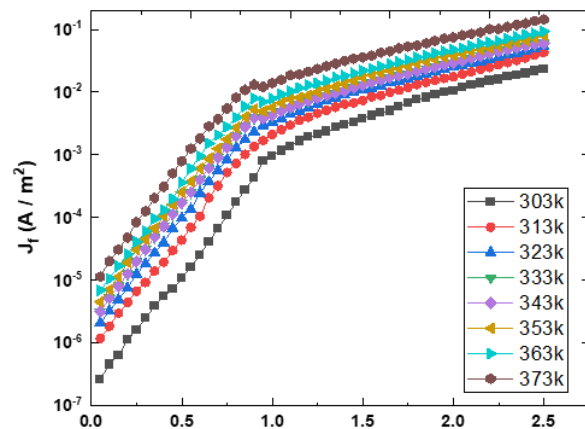


Figure 4 Plots of the forward and reverse bias at room temperature.

Figure 5 shows two different regions indicating the presence of two different conduction mechanisms. In the first region at low voltage ($V < 1$ volt), the dark forward J-V characteristics are presented in Figure 5.

For a given temperature, the forward current gradient was found to be nearly constant, and the quality factor was identified. The series resistance decreases with increasing cell temperature.



5 Variation of J_f with V of DBM/n Si cell.

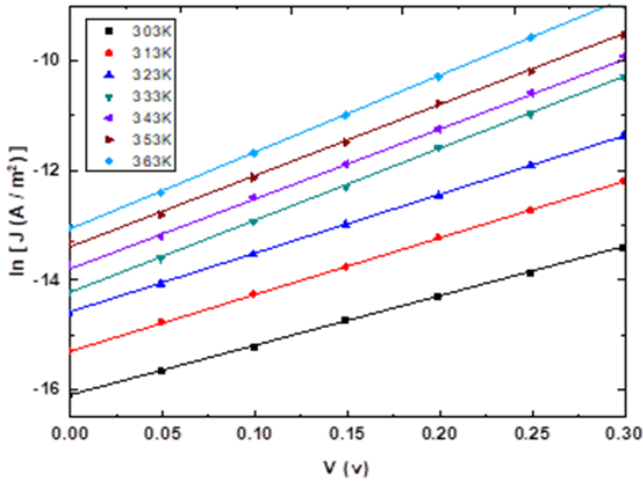


Figure 6 Variation of $\ln J_f$ with V of DBM/n Si cell at low voltage

It is suggested that the main current transport mechanism in this region is the tunneling mechanism, and the voltage dependence of the transient current can be expressed as [5]:

$$J = J_{01} [\exp(\alpha V)]$$

Where α is an independent constant of temperature, the data of Figure 6 were analyzed using equation 2, and the parameter α was found to be 12 V^{-1} . On the other hand, the reverse saturation current density J_{01} can be calculated by extrapolating the forward current density curves to zero voltage. According to multi-step tunneling mechanisms, J_{01} should change exponentially with temperature and given by

$$J_{01} = J_{00} \exp(\beta T)$$

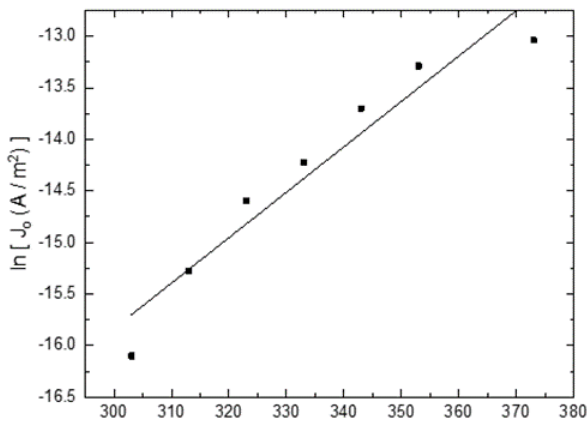


Figure (7): Variation of J_f with V of DBM/n Si cell.

Where β is a constant independent of the applied voltage, Figure 7 shows the plot as a function of temperature, and a straight line is obtained, indicating the existence of a multi-level tunnelling mechanism. The value of β is determined by the slope of the straight line obtained and is 0.045 K^{-1} .

The ratio α/β can be used to determine the change in the built-in voltage (V_{bi}) with respect to absolute temperature (T) as:

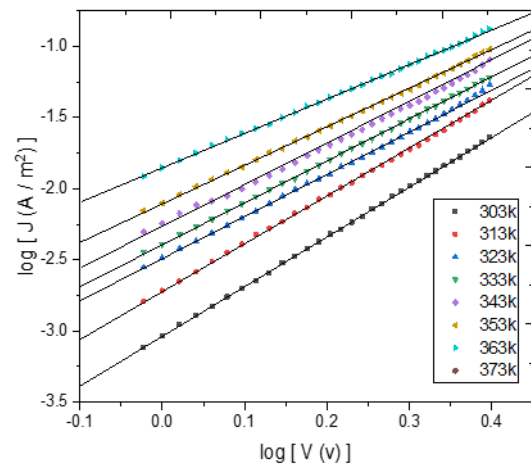


Figure 8 Variation of $\log (J)$ with $\log (V)$ at higher forward voltage bias for DBM/n Si cell.

$$\frac{dV_{bi}}{dT} = -\frac{\beta}{\alpha}$$

The calculated value of dV_{bi}/dT is equal to 3.75×10^{-3} V/K. The following relationship can give the number of steps (R) required for an electron to traverse the depletion region.

$$\alpha = (8/3h) (m^* \epsilon' / RN_1)^{1/2}$$

Where h is represent Planck's constant, N_1 is the acceptor concentration in n-Si, ϵ' is the dielectric constant of n-Si, and m^* is the effective mass of the electron ($m^* = 0.56 m_e$). It was found that R is about 2.11×10^5 steps.

Another conduction mechanism emerges in the second region, which is defined by high voltage ($V > 1$ volt). Plotting the current density on a logJ-logV scale, as shown in Figure 8, reveals a power dependence on voltage with a slope of about two. as depicted in Figure 8. This power dependence proposes that the dark current is a space-charge-limited current (SCLC) controlled by a single trap level.

According to Lambert's theory, the relation for the current density, in this case, is given by [6]

$$J_{SCLC} = \frac{9}{8} \epsilon_2 \mu \theta \frac{V^2}{d^3}$$

The trapping factor, denoted as θ , represents the ratio of free charge to trapped charge. It is determined by factors such as the thickness of the DBM thin film (d), the dielectric constant of DBM (ϵ_2), and the hole mobility (μ). [7]

$$\theta = \frac{N_v}{N_{t(s)}} \exp\left(\frac{-E_t}{k_B T}\right)$$

Boltzmann's constant, indicated by k_B , the total trap concentration at energy level E_t above the valence band edge, indicated by $N_{t(s)}$, and the density of states that is effectively present at the valence band edge, called as N_v .

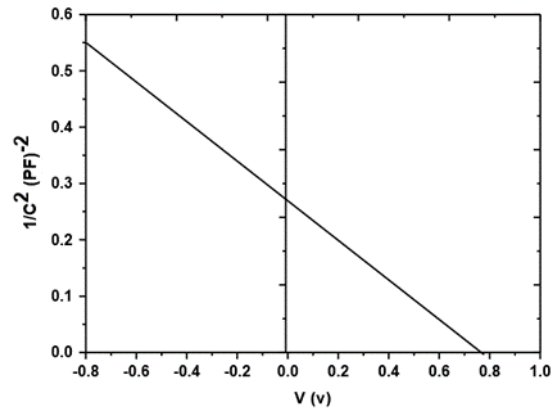


Figure 9 C^2 -V characteristic for DBM/n-Si cell.

By extending the straight line to cross the voltage axis at $1/C^2 = 0$, the built-in voltages were determined. The donor concentration in DBM is shown by the slope of the straight lines. Table 1 shows the estimated values for the device C_0 's built-in voltage, donor concentration, and capacitance at zero bias.

Table 1: Values of V_{bi} , N_2 , and C_0 of DBM/p-Si cell room temperature.

	C_0 (pF)	V_{bi} (volts)	N_2 (10^{11} cm^{-3})
Fabricated cell	1.92	0.78	3.5

The experimental efficiency of the solar cell is given by the following equation:

$$\eta\% = \frac{P_m}{P_{in}} = \frac{FF \cdot V_{oc} I_{sc}}{P_{in}} \times 10$$

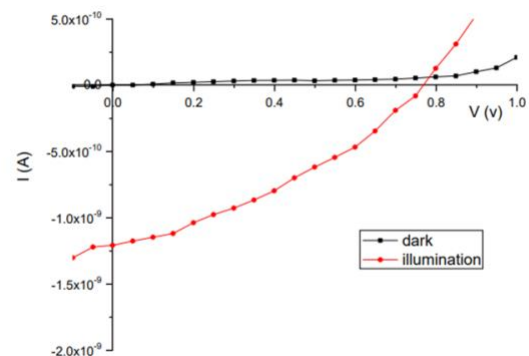


Figure 10 Load J-V characteristics under 20 mW/cm^2 illumination for DBM/n-Si cell.

Where P_{in} is the estimated light intensity impinging on the cell, expressed in mW/cm^2 , and FF is the filling factor, as determined by: -

$$FF = \frac{V_{max}I_{max}}{V_{oc}I_{sc}}$$

$$J_{sc} = \frac{I_{sc}}{A}$$

where V_{max} and I_{max} are the potential and current at the greatest power point. Consequently, the maximum power that the cell can produce is indicated by:

$$P_{max} = V_{max}I_{max} = FF \cdot V_{oc}I_{sc}$$

Table 2: The photovoltaic parameters of the DBM/n-Si cell at room temperature.

The solar cell efficiency was determined without adjusting for reflection or electrode absorption losses, yielding approximately 1.48%. This aligns with the values observed for organic materials as listed in Table 2.

	I_{sc} (Amps)	V_{oc} (volts)	F	I_{max} (Amps)	V_{max} (volts)	η %
a fabricated cell	1.2×10^{-9}	0.76	0.361	7.5×10^{-10}	0.44	1.48

4. Conclusion

A fabricated heterojunction cell was prepared as a thin film p-DBM/n-Si on a single-crystal substrate by using thermal evaporation. By measuring the dark current density–voltage (J-V) and capacitance-voltage (C-V) at different values of temperatures, we find that the rectification ratio $RR=4043$ at 1V. We found that there are two types of mechanisms. The first one, at voltages less than 1 volt, is a step tunneling mechanism with 2.11×10^5 steps, and the second one, at high voltage of more than 1 volt, is space–charge–limited current (SCLC), controlled by a single trap level. By measuring (C-V), we find that the junction is abrupt, the built-in voltage equals 0.78 volts, and the initial capacitance=1.9 pf.

Finally, we estimate the solar cell parameters V_{oc} (open circuit voltage) = 0.76 volts, I_{sc} (short-circuit current) = 1.2×10^{-9} A, and the cell efficiency = 1.48% by illuminating the cell with a lamp whose power density equals 20 mW/cm^2 .

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References and Sources

1. D.I.K. Petritsch, "Organic Solar Cell Architectures," PhD Thesis, (2002).
2. J. Nelson, *Material Today*, 5(2002)20.
3. A.A.A. Darwish, E.F.M. El-Zaidiaa, Saleem I. Qashou, *Physica B: Condensed Matter* (2019) 558
4. M.M. El-Nahass, H.S. Metwally, H.E.A. El-Sayed, A.M. Hassanien, *Synthetic Metals*(2011) 161
5. Ahmed M. Nawar • Mohamed Abd Elsalam • Ahmed M. El Mahalawy M. M. El Nahass, *Applied Physics A* (2020) 126:113.
6. S.E. Al Garni, A.A.A. Darwish, *Solar Energy Materials & Solar Cells* (2017) 160
7. M.M. El-Nahass, W.M. Desoky, *Optik* (2018).
8. N. M. Khusayfan, E. F. M. El-Zaidia, M. M. El-Nahass, *Silicon* (2018).
9. Saleem I. Qashou, Riad S. Masharfe, S. Alfadhli, A.A.A. Darwish, *Physica B: Physics of Condensed Matter*, (2021) 618.

10. H.M. Zeyadaa, M.M. El-Nahassb, E.M. El-Menyawyc, A.S. El-Sawaha, *Synthetic Metals* (2015) 207. 19.
20.
21.
22.
11. H.M. Zeyadaa, M.M. El-Nahassb, M.M. El-Shabaan, *Synthetic Metals* (2016) 220. 23.
24.
12. M. Ashida, *Bull. Chem. Soc. Jpn.*, 39 (1966) 2625.
13. P.S. Vincett, Z.D. Popovic, L. McIntyre, *Thin Solid Films*, 82 (1981) 357.
14. M. M. El-Nahass, A. A. M. Farag, K. F. Abd-El-Rahman, A. A. A. Darwish, A thesis submitted for the degree of Master of Teacher Preparation in Science, Study of Some Physical Properties of Nickel Phthalocyanine Thin Films, 2004.
15. James R. Connolly, for EPS 400-002, Introduction to X-Ray Powder Diffraction, Spring 2005.
16. Technique for the growth of stoichiometry thin films," was authored by Sharma D et al. and was published in the *International Journal of Research in Pharmacy and Science* in 2018, volume 8, issue 2, pages 21-25.
17. B.L. Sharma and R.K. Purohit, "Semiconductor Heterojunction," Pergamon Press, New York (1974) 73.
18. *Physics of Semiconductor Devices* by M.S. Sze, published in its 2nd edition by Wiley, New York, in 1981.