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Characterization and photovoltaic performance of organic device based on AlPcCl/p-Si heterojunction

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ABSTRACT

Analysis of electrical properties Au/AlPcCl/p-Si/Al as p–p+ heterojunction was studied. The dark forward current–voltage characteristics showed a thermionic emission mechanism at low voltage region ($V \leq 0.26$ V), while at high voltage region ($V \geq 0.32$ V); the operating conduction mechanism was found to be space charge limited current. From (I–V) curves, the junction parameters such as series resistance (R_s), ideality factor (n) and effective barrier height (Φ_b) were determined at temperatures range (308–378 K). The series resistance and barrier height values of AlPcCl/p-Si heterojunction estimated from Cheung's and Norde's methods are strongly temperature dependent especially towards the lower temperatures. The capacitance–voltage (C–V) characteristics of AlPcCl/p-Si devices were also investigated. The built-in potential obtained from the (C–V) measurements was found to be 0.49 eV. Solar cell parameters were evaluated under illumination of 6 mW/cm^2 and the power conversion efficiency was estimated as 2.6%.

1. Introduction

Organic semiconducting materials are of particular interest, since they possess a prosperous optoelectronic, electrical and processing properties for designing and fabrication of electronic devices [1]. Among these materials, a series of phthalocyanines represent a large family of heterocyclic conjugated molecules with high chemical stability. Phthalocyanines as a class of organic materials are generally thermally stable and can easily be deposited as thin films with high quality by thermal evaporation without dissociation. Metal phthalocyanines (MPc's) have gained considerable attention in recent years because they have been successfully applied in many applications such as gas sensors [2,3], solar cells [4–6] and light emitting diodes [7,8]. Studying different properties of MPc's thin films have attracted the researchers over the last few years [9,10]. Relatively few studies have focused on the halogenated MPc's although there is evidence that they may exhibit properties suitable for gas sensing applications [11]. It has also been shown that the halogenated Pc's exhibit a remarkable morphological and thermal stability over a larger temperature range compared to unhalogenated Pc's [12].

The present study deals with AlPcCl/p-Si heterojunction that prepared by conventional thermal deposition technique. The working conduction mechanism and the dynamic capacitance–voltage (C–V) methods were applied to determine the different junction parameters such as series resistance, ideality factor, built-in potential and type of the formed junction. Also the photovoltaic properties of this junction were investigated.

2. Experimental techniques

The AlPcCl powder used in this study was obtained from Sigma–Aldrich Chem. Co. The p-Si substrate was etched using chemical etching solution of $HF:HNO_3:CH_3COOH$ in ratio of 1:6:1. After etching, the Si substrate was washed with distilled water and then by ethyl alcohol several times. The Si substrate was coated on one side by Al electrode and on the another side by AlPcCl film of thickness 518 nm, using thermal evaporation technique, under vacuum of 10^{-5} Pa by using Edwards, E306A. The AlPcCl film was coated by Au-mesh to be used as upper contact electrode. We used a high impedance programmable electrometer (Keithley 2635A) to study the dark current–voltage (I–V) measurements of the fabricated junction at temperatures range (308–378 K). The temperature was measured directly by NiCr–NiAl thermocouple. The dark (C–V) characteristics of the fabricated cell were measured at room temperature and 1 MHz, using a computerized CV—410 m (model 4108). All measurements were performed in a complete dark oven. In order to obtain the solar cell parameters, the loaded I–V characteristics were studied at room temperature and under tungsten lamp of power (6 mW/cm^2) that incident normally on the

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heterojunction. The intensity of the incident light was measured using a digital luxmeter (BCHA, model 93408).

3. Results and discussion

Study of current–voltage (I–V) characteristics provided a valuable information about the junction parameters such as diode quality factor (n), saturation current (I_o), series resistance (R_s) and type of transport conduction mechanism. The (I–V) characteristics of Au/AlPcCl/p-Si/Al heterojunction, in a temperature range (308–378 K) and in the voltage range (0–2 V) in both forward and reverse directions, are shown in Fig. 1. It is clear from the figure that the curves exhibit diode like behavior and the current increases with increasing temperature. The barrier at the interface limits forward and reverse carriers to flow across the junction, where the built-in potential could be developed. The semilogarithmic plots of the forward current–voltage characteristics of AlPcCl/p-Si heterojunction at different temperatures are shown in Fig. 2. Two distinct regions characterize these curves indicating two different conduction mechanisms. At low positive voltage ($V \leq 0.26$ V), the current increases exponentially with the applied voltage, while at high positive voltage ($V \geq 0.32$ V), the current is deviated from the straight line due to a voltage drop across the series resistance associated with the neutral region of a semiconductor and interface states [13]. According to Fig. 2, the (I–V) characteristics can be analyzed using the diode equation [14,15]:

$$I = AA^{*}T^{2}\exp\left(\frac{-q\phi_{b}}{K_{B}T}\right)\left[\exp\left(\frac{V - IR_{s}}{nK_{B}T}\right)\right] \tag{1}$$

where q is the electronic charge, V is the applied voltage, n is the diode ideality factor, K_B is the Boltzmann constant, T is the absolute temperature, A is the effective area, A^* is the effective Richardson constant that takes a value 32 A/cm^2 K^2 for p-Si [16–18] and ϕ_b is the zero-bias barrier height which is expressed as:

$$\phi_{b} = \frac{K_{B}T}{q}\ln\left(\frac{AA^{*}T^{2}}{I_{o}}\right) \tag{2}$$

where I_o is the saturation current. At low voltage region, from slopes and intercepts of the obtained straight lines, we can get the values of diode ideality factor, barrier height and saturation current, respectively. The obtained values of ideality factor and barrier height are plotted against temperature as shown in Fig. 3. It is seen that the value of ϕ_b increases while ideality factor, n decreases with increasing temperature. Temperature dependence of the ideality factor and the barrier height can be elucidated on the basis of heterogeneity barrier height model. The fluctuations in the barrier height are always present even in the most carefully fabricated diodes [19,20]. This behavior indicates that the thermionic emission mechanism is the operating mechanism of the junction under investigations. To confirm that thermionic emission mechanism is the operating conduction mechanism at low voltage region, the relation between ln (I_o/T^2) and 1000/T is plotted as shown in Fig. 4. The obtained straight line ensures that the thermionic mechanism is the predominant mechanism [21].

The relation between log I vs log V, at high forward biasing ($V \geq 0.32$ V) and different temperatures is shown in Fig. 5. A super quadratic dependence of current on the voltage of the form I–V^m was observed. Values of m, are calculated from the slopes of the straight lines in the figure and were found to be greater than 2 indicating that the space charge limited current (SCLC) controlled by the distribution of trap level is the operating mechanism in this region. The current in SCLC mechanism is given by [22]:

$$I = e\mu N_{\upsilon}\left(\frac{\varepsilon\varepsilon_{o}}{eP_{o}K_{B}T_{t}}\right)^{l}\left(\frac{V^{l+1}}{d^{2l+1}}\right) \tag{3}$$

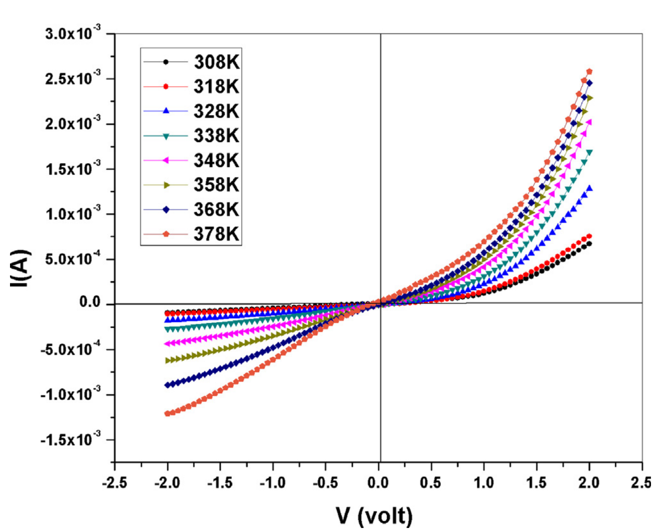

Fig. 1. Dark I–V characteristics of AlPcCl/p-Si heterojunction at different temperatures in both forward and reverse directions.

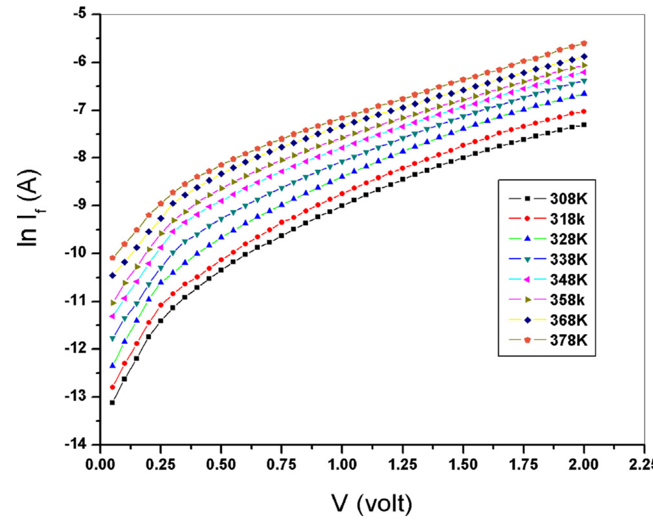

Fig. 2. Variation of (ln I_f) with forward bias voltage for AlPcCl/p-Si heterojunction at different temperatures.

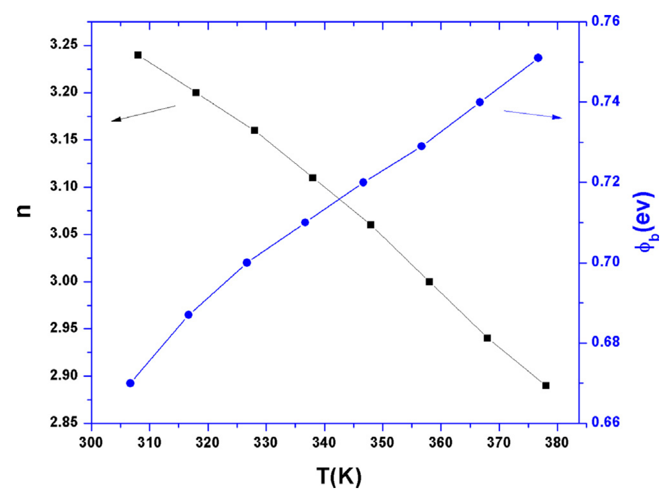

Fig. 3. Temperature dependence of ideality factor (n) and barrier height (ϕ_b) of AlPcCl/p-Si heterojunction.