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Improvement of diode parameters in Al/n-Si Schottky diodes with Coronene interlayer using variation of the illumination intensity

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ABSTRACT

In present work, Coronene thin films on Si wafer have been deposited by the spin coating method. It has been ultimately produced Al/Coronene/n-Si/In Schottky diode. Current–voltage (*I-V*) measurements have been used to determine the effect of illumination intensity in the Schottky diodes. The barrier height (Φ_B) values increased as ideality factor (n) values decreased with a increase in illumination intensity. The Φ_B values have been found to be 0.697 and 0.755 eV at dark and 100 mW/cm^2, respectively. The n values have been found to be 2.81 and 2.07 at dark and 100 mW/cm^2, respectively. Additionally, the series resistance (R_s) values from modified Norde method and interface state density (N_{ss}) values using current-voltage measurements have been determined. The values of R_s have been found to be 1924 and 5094 Ω at dark and 100 mW/cm^2, respectively. The values of N_{ss} have been found to be 4.76×10^{12} and 3.15×10^{12} eV^{-1} cm^{-2} at dark and 100 mW/cm^2, respectively. The diode parameters are improved by applying the variation of illumination intensity to the formed Schottky diodes.

1. Introduction

Recently, the use of organic molecule layers in Schottky diodes has garnered significant momentum for the optoelectronic and electronic devices since organic materials have cheaper and simpler fabrication process compared with inorganic materials [1–5]. It has been observed that organic materials can be used to form rectifying junctions with inorganic semiconductors and metal [6–8]. A large number of investigations have been carried out on electrical and photovoltaic behavior of organic/inorganic semiconductor device in the different illumination intensity [9–15].

Many efforts have been reported to achieve a modification of the barrier height using an organic semiconducting layer [9–15]. Inorganic-organic contacts such as n-Si/9,10-H_2BaP [10], n-Si/Oxazine (OXZ) [11], n-Si/CoPc [4], n-Si/phenolsulfonphthalein (PSP) [12], n-Si/PTCDA [13], n-Si/DMFC [14], and n-Si/Anthracene [15] have been prepared in literature and then their electrical and photoelectrical properties have been evaluated. Özerden et al. [10] have determined the electrical and photoelectrical properties of the Ag/9,10-dihydrobenzo[a]pyrene-7(8H)-one (9,10-H2BaP)/n-Si contact, and reported that the barrier height of the device was lower than that of Ag/n-Si Schottky diode. Farag et al. [11] have fabricated OXZ organic compound on n-Si substrate by spin coating process and the electrical characterization. They have determined some junction parameters of this structure by the electrical and photoelectrical characterizations such as capacitance–voltage (*C–V*) and current-voltage (*I–V*). Wahab et al. [4] have studied the fabrication and characterization of cobalt phthalocyanine (CoPc)/n-silicon heterojunction diode. The authors have also obtained the ideality factor and barrier height values of the heterojunctions.

Coronene among organic semiconductor compounds is considered a good candidate for organic semiconductor device fabrication such as photovoltaic cell and Schottky diode [16–18]. We have chosen Coronene as organic material for the fabrication organic/inorganic device. Coronene is known with molecular formula $C_{24}H_{12}$. Coronene is the simplest hydrocarbon in which benzene rings completely surround a central aromatic nucleus.

A detailed work on device properties and an understanding of the possible effects of illumination is a major step in the development of the Coronene based photodiodes. The propose of this paper is to characterise the variation of ideality factor, barrier height, series resistance and interface states in Al/Coronene/n-Si structures under dark and illumination and study the effect of Coronene organic film on the electrical characteristics. For this purpose, the photocurrent

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characteristics of the Schottky diode have been studied under dark and 10, 30, 60, and 100 mW/cm^2 illumination intensity. The dependence of illumination intensity of electrical characteristics of the main parameters such as barrier heights, ideality factors, interface state densities and series resistances determined from various techniques has been examined. Moreover, the capacitance-conductance-voltage (*C-G-V*) measurements in the 1 MHz have been made to determine the characteristic parameters of the diode. It is important to determine device parameters of the diode under illumination for its potential application in photosensors.

2. Experimental

In the present experiment, Coronene was obtained from Sigma Aldrich and toluene was used as a solvent. the Si wafer grown by Czochralski process has a P-doped, (100) orientation, 20 Ω cm resistivity and 380 µm thickness. To remove the oxide layer, the n-Si surface has been cleaned by the RCA process [19,20]. Indium (In) and Aluminium (Al) metals with 150 nm thickness have been thermally grown by using basket-shaped tungsten filament in evaporation system (Nanovak, 300-2TH1SP) for the ohmic and rectifying contacts, respectively. Coronene thin film has been coated on n-Si by the spin coating process (Laurell spin coater, WS-650-23 model). Finally, the structure of Al/Coronene/n-Si/In Schottky diode has been constructed. The current-voltage (*I-V*) characteristics of diode were performed in dark and under the different light intensity by means of Keithley 4200 semiconductor characterization system. The characteristics of photodiode have been investigated by using solar simulator (Sciencetech (SF-300-B) small collimated beam Solar Simulator, 300 W, Class ABA) in the light intensity range of 10–100 mW/cm^2.

3. Results and discussion

3.1. Current–voltage (I-V) characteristics of Al/Coronene/n-Si/In diode in dark and illumination intensity

A typical set of semilogarithmic *I–V* characteristics of the investigated Al/Coronene/n-Si Schottky diode for dc bias voltages ranging from −2 V to +2 V at dark and various illumination intensity (10–100 mW/cm^2) is shown in Fig. 1. From the figure, the diode shows a good rectification behavior. The rectification ratio of the Coronene/n-Si structure at ± 2 V has been calculated as 6.15. The relevant diode parameters have been calculated according to thermionic emission model before and after illumination. Therefore, the diode characteristics from the *I-V* are analyzed as [21–27]

$$I = I_0\left[\exp\left(\frac{qV}{nkT}\right) - 1\right];\quad I_0 = AA^*T^2\exp\left(-\frac{q\Phi_{B0}}{kT}\right) \qquad (1)$$

where Φ_{B0} is the Schottky effective barrier height, I_0 is the saturation current, q is the electronic charge, T is the absolute temperature in Kelvin, n is the ideality factor, A is the contact area, and A^* is the effective Richardson constant (A^*= 112 A K^{-2} cm^{-2} for n-Si [21,22]). It is calculated the n values from the slope and Φ_{B0} values from extrapolated I_0 of the straight-line region higher than $3kT/q$ region of Fig. 1 according to the following equations [28,29]:

$$n = \frac{q}{kT}\left(\frac{dV}{d\ln I}\right) \text{ and } \Phi_{B0} = \frac{kT}{q}\ln\left(\frac{AA^*T^2}{I_0}\right) \qquad (2)$$

The *I–V* measurements have been also carried out to investigate the effect of light on the electrical characteristics of the Al/Coronene/n-Si diode under illumination intensities 10, 30, 60, and 100 mW/cm^2 and in the dark. From the figure, it is observed that the structure has very strong light sensitivity and the reverse bias current of the diode increases with the increasing light intensity. This change of the Al/Coronene/n-Si Schottky diode is a conventional tendency of a photodiode [10,30]. Furthermore, This shows that the resistance of the diode decreases by the illumination [30]. Furthermore, according to Eq. (2) and Fig. 2, the values of Schottky barrier height and the ideality factor have been determined to be Φ_{B0}= 0.697 eV and n= 2.81 at dark and Φ_{B0}= 0.755 eV and n= 2.07 for 100 mW/cm^2, respectively. Furthermore, the n value (n= 2.81) for Coronene/n-Si contact at dark is lower than the value of 3.14 given for new fuchsin/n-Si contact [35] and the value of 3.48 given for Aniline green/n-Si contact [36] but is higher than the value of 2.41 given for Anthracene/n-Si contact [15]. Fig. 2 shows the variation of n and Φ_{B0} with illumination intensity (P). As seen from Fig. 2, while the ideality factor decreases almost linearly, the barrier height increases linearly with the illumination intensity. It is an expected situation under illumination intensity for Schottky barrier

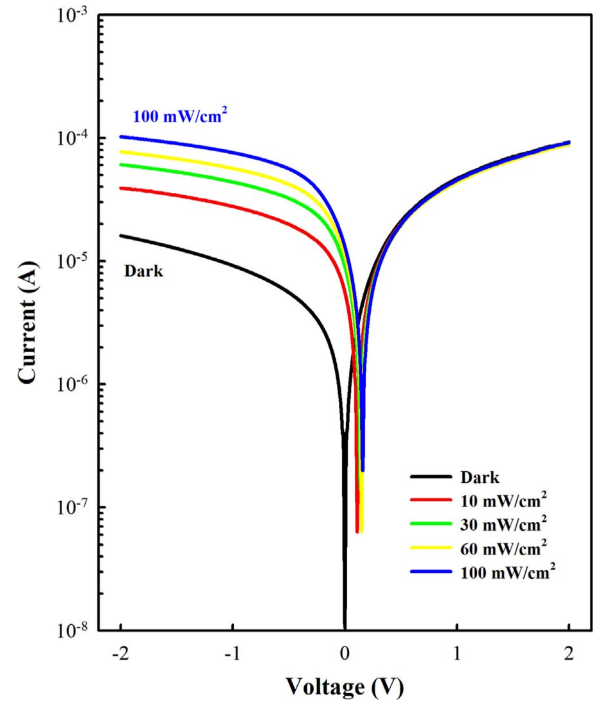

Fig. 1. Semilogarithmic *I–V* curves obtained from the *I–V* data of the Al/Coronene/n–Si diode under dark, 10, 30, 60 and 100 mW/cm^2 illumination intensities.

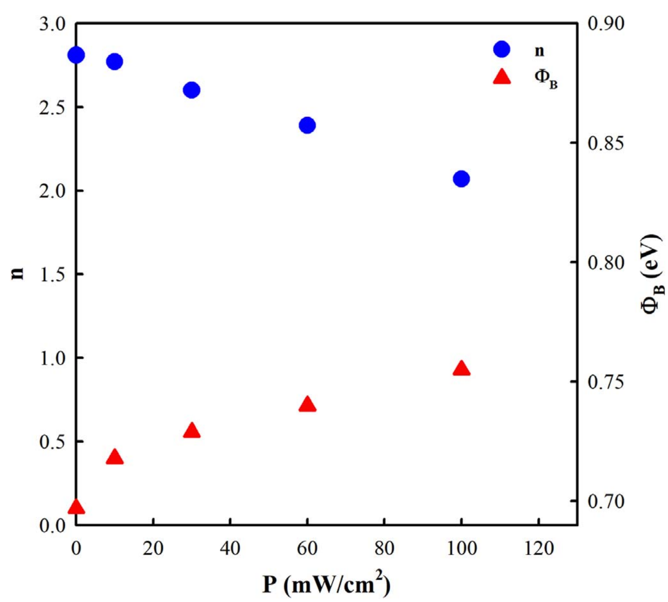

Fig. 2. The illumination intensity dependence of the ideality factor (n) and the Schottky barrier height (Φ_B).