

The analysis of capacitance-conductance-voltage (C-G-V) characteristics of organic semiconductor diode with pyrene-imine

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Pyrene-imine (dimethyl (E)-5-(((4,6-dihydropyren-1-yl)methylene)amino)isophthalate, the compound containing an pyrene-imine group) thin film was prepared on n-Si substrate with spin coating technique. Atomic force microscopy (AFM) images showed that the surface of the pyrene-imine on Si wafer was uniform. In the present work, Au/Pyrene-imine/n-Si/In Schottky diode were fabricated and capacitance/conductance characteristics were studied in the frequency range from 100 kHz to 1 MHz at dark and room temperature. The values of conductance and capacitance strongly depend on the frequency and voltage. The studied parameters such as series resistance (R_s) and interface state density (N_{ss}) were obtained by the capacitance-conductance-voltage (C-G-V) measurements. The R_s values of the studied diode were obtained as 816Ω for 100 kHz, 479Ω for 300 kHz, 336Ω for 500 kHz and 173 Ω for 1 MHz. The N_{ss} values of the studied diode were obtained as $2.08 \times 10^{11} \text{ cm}^{-2} \text{ eV}^{-1}$ for 100 kHz, $1.56 \times 10^{11} \text{ cm}^{-2} \text{ eV}^{-1}$ for 300 kHz, $1.52 \times 10^{11} \text{ cm}^{-2} \text{ eV}^{-1}$ for 500 kHz and $8.16 \times 10^{10} \text{ cm}^{-2} \text{ eV}^{-1}$ for 1 MHz. As a results, the Au/Pyrene-imine/n-Si/In Schottky diode can be utilized in capacitance applications in industry.

Keywords: Pyrene-imine, Schottky diode, capacitance-conductance-voltage, series resistance

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1. Introduction

In recent, metal-organic material-semiconductor (MOMs) structures produced by depositing of an organic thin material on a semiconductor wafer have gained notice due to their broad utilize in electronics such as detectors, diodes, and solar cells [1-4]. Organic thin films present some advantages such as low-cost manufacturing, stability, and widespread area applications [5-7]. They are needed as key pieces in the production of semiconductor electronic devices such as organic photovoltaic devices, Schottky barrier diodes, and rechargeable batteries [8-10].

Many researchers have investigated the capacitance-voltage and conductance-voltage properties of organic thin film deposited on inorganic semiconductors [11-14]. Yahia et al. [11] have designed Au/Pyronin-Y/p-Si Schottky diode. They have reported that the capacitance-voltage and conductance-voltage characteristics of the diode and the

values of series resistance of the diode. Tuğluoğlu et al. synthesized Perylene-monoimide (PMI) organic material and prepared Au/PMI/n-Si diode [12]. They studied using frequency dependent interface state properties of diode in detail by using capacitance-conductance-voltage (C-G-V) characteristics. They have reported that the series resistance and interface state density values of the diode for different frequencies.

Herein, we report the capacitance and conductance characteristics of a new type of Au/pyrene-imine/n-Si/In Schottky diode by using these characteristics, it is aimed to determine the series resistance and interface distribution depending on the frequency. For this purpose, measurements were taken in the -1 to +1 volt range and 100k Hz -1 MHz frequency range. Frequency-dependent characteristic parameter changes were determined. In this manner, it is aimed that fabricated diode are utilized in electronic device applications.

2. Experimental

In this study, the Si wafer has phosphor doped (n type), 1–20 Ω -cm resistivity, 525 μm thickness, and (1 0 0) surface orientation. The Si wafers purchased from University Wafer were cleaned by RCA technique to eliminate oxide layer and impurity. [15]. Vacuum evaporation technique was used to collect the In metal (150 nm) for ohmic contact and Au metal (150 nm) for rectifying contact to n type Si wafer. To prepare the aqueous solution of pyrene-imine for utilize in the spin coater, 10 mg of pyrene-imine compound were dissolved in 10 ml of chloroform. This solution was used to deposit pyrene-imine on n-Si wafer by spin coating. Spin coating conditions are 2000 rpm for 60 seconds and kept it to dry in a vacuum oven (3×10^{-4} Torr) for 3 h. Finally, Au/Pyrene-imine/n-Si/In Schottky diode was prepared. Figure 1 presents the schematic diagram of Au/Pyrene-imine/n-Si/In Schottky structure. To study the interface state density and series resistance characteristics of the prepared diode, the measurements were taken in the vary from -1 V to +1 V and from 100 kHz to 1 MHz frequency. Atomic force microscope (AFM) measurements were performed using Nano Magnetics. $C-V$ and $G-V$ characteristics were measured using a Keysight E4990A Impedance Analyzer at room temperature.

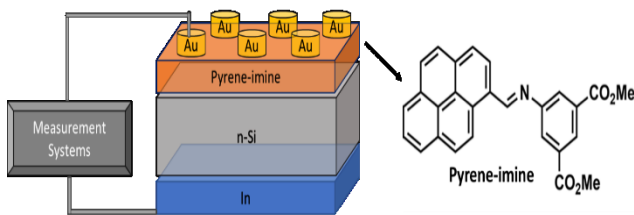


Figure 1: Schematic diagram of Au/Pyrene-imine/n-Si/In Schottky diode structure

3. Results

To many organic diode applications, the formation of uniform organic thin films is very important [16]. The surface morphology of Pyrene-imine was observed using 2D and 3D atomic force microscopy (AFM) images. The AFM analysis (Fig. 2) displayed a root mean square value of 175 nm, average value of 1131 nm, ten point height of 1583 nm, peak to peak value of 3134 nm, and average roughness value of 104 nm. The results show that Pyrene-imine is an important organic material for diode fabrication with reduction of leakage current.

Figure 3 displays capacitance–voltage ($C-V$) curves of the fabricated diode as a function of voltage at 100 kHz, 300 kHz, 500 kHz, and 1 MHz frequencies, from which it can be observed that the C value for the fabricated diode decrease as the applied frequency increases. It is clearly that the $C-V$ plots rely on the Pyrene-imine organic layer. It is observed from Fig. 3 that the values of capacitance decrease with the frequency for the inversion, depletion and accumulation areas, while the values of capacitance increase with the voltage. The capacitance values of the fabricated diode are

extremely sensitive to the interface states (N_{ss}) in Schottky type structures.

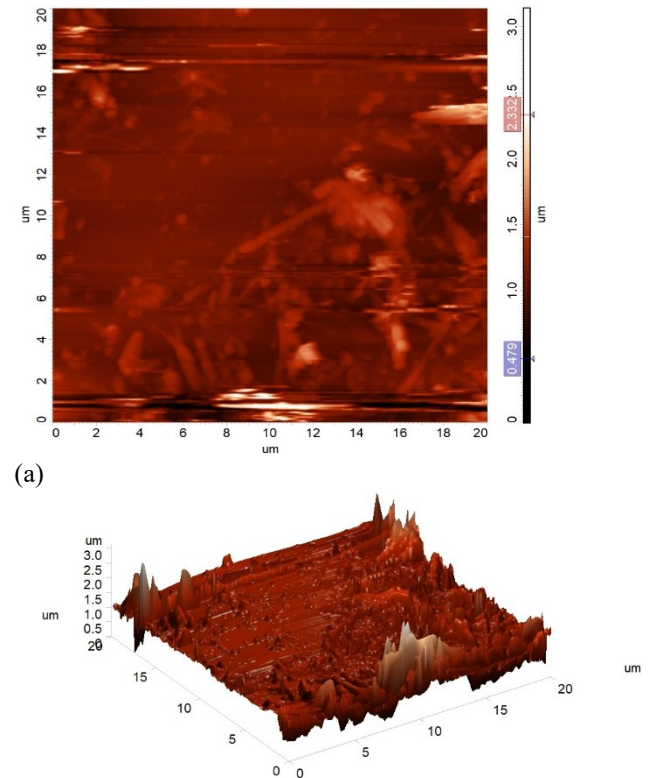


Figure 2: a) 2D and b) 3D AFM topographic surface photos of Pyrene-imine on n-Si wafer.

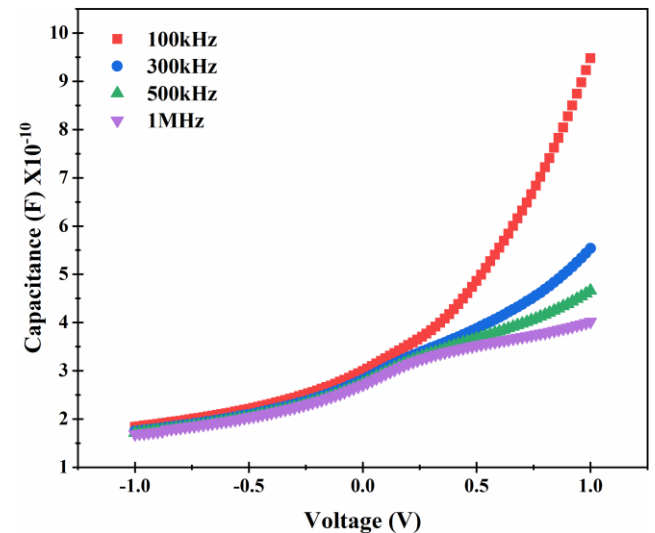


Figure 3: Graphs of $C-V$ of the Au/Pyrene-imine/n-Si diode at different frequencies

Figure 4 displays conductance–voltage ($G-V$) curves of the fabricated diode as a function of voltage at 100 kHz, 300 kHz, 500 kHz, and 1 MHz frequencies, from which it can be observed that the G value for the fabricated diode increase as the applied frequency increases. It was reported that this result is caused by the series resistance (R_s) [17].

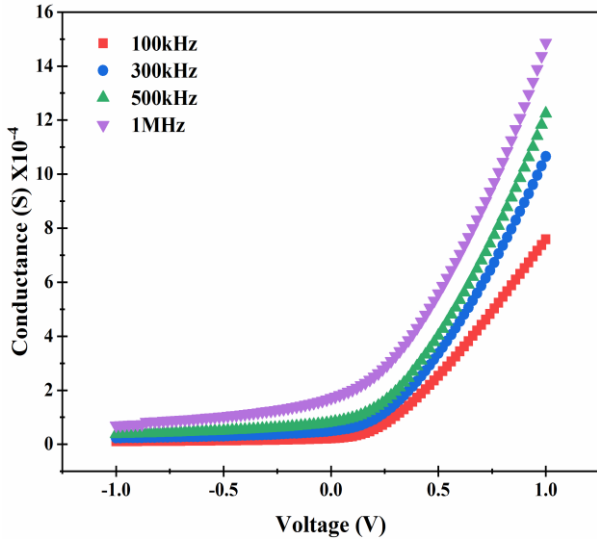


Figure 4: Graphs of $G-V$ of the Au/Pyrene-imine/n-Si diode at different frequencies

The interface states (N_{ss}) and series resistance (R_s) in electronic devices are the most important parameters changing the $C-V$ and $G-V$ characteristics and performance of the produced device. The R_s values of the fabricated diodes were determined using the following relation for each voltage value [18]:

$$R_s = \frac{G}{G^2 + (\omega C)^2} \quad (1)$$

Figure 5 displays the R_s values determined from Eq. (1) according to bias voltage. From Fig. 5, the R_s value for all frequency measurements has a peak point and the magnitude of highest R_s value decreased with increased frequency.

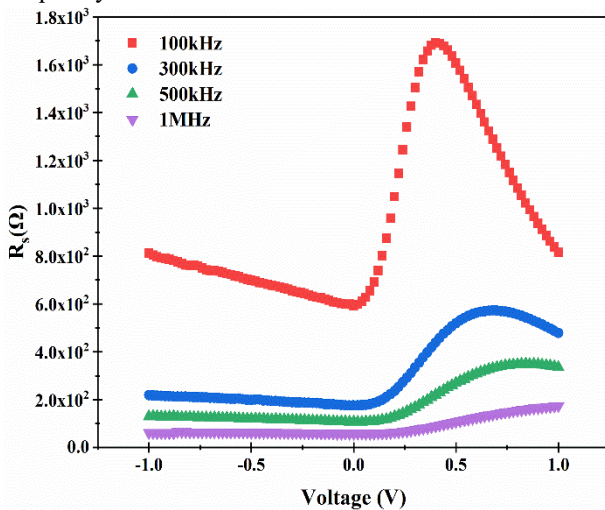


Figure 5: Graphs of R_s-V of the Au/Pyrene-imine/n-Si diode at different frequencies

Also, The R_s values of the studied diode were obtained as 816Ω for 100 kHz, 479Ω for 300 kHz, 336Ω for 500 kHz and 173Ω for 1 MHz. Çavdar et. al. [19] investigated the frequency and voltage-dependent series resistance in Schottky type structures. They observed a peak in $R_s - V$ plots.

The interface states (N_{ss}) values of the fabricated diode were determined using the Hill-Coleman equation [20] for each frequency value. The N_{ss} values of the studied diode were obtained as $2.08 \times 10^{11} \text{ cm}^{-2} \text{ eV}^{-1}$ for 100 kHz, $1.56 \times 10^{11} \text{ cm}^{-2} \text{ eV}^{-1}$ for 300 kHz, $1.52 \times 10^{11} \text{ cm}^{-2} \text{ eV}^{-1}$ for 500 kHz and $8.16 \times 10^{10} \text{ cm}^{-2} \text{ eV}^{-1}$ for 1 MHz. Çavdar et. al. [19] investigated the frequency-dependent interface states (N_{ss}) in Schottky type structures. They reported that as the frequency increases, the values of the interface states decrease and this is due to the carriers' inability to follow the frequency at high frequencies.

4. Conclusion

In this work, Atomic force microscopy (AFM) images showed that the surface of the pyrene-imine on Si wafer was uniform. capacitance-voltage ($C-V$) and conductance-voltage ($G-V$) methods were used to characterize Au/n-Si Schottky diodes with pyrene-imine organic interfacial. The forward and reverse bias $C-V$ and $G-V$ characteristic of the Schottky diode were measured in the voltage vary from -1V to 1V and from 100 kHz to 1 MHz frequencies. As the frequency values increased, the capacitance and series resistance values decreased, while the conductivity values increased. This is expected for a Schottky diode. The R_s values of the studied diode were obtained as 816Ω for 100 kHz, 479Ω for 300 kHz, 336Ω for 500 kHz and 173Ω for 1 MHz. The N_{ss} values of the studied diode were obtained as $2.08 \times 10^{11} \text{ cm}^{-2} \text{ eV}^{-1}$ for 100 kHz, $1.56 \times 10^{11} \text{ cm}^{-2} \text{ eV}^{-1}$ for 300 kHz, $1.52 \times 10^{11} \text{ cm}^{-2} \text{ eV}^{-1}$ for 500 kHz and $8.16 \times 10^{10} \text{ cm}^{-2} \text{ eV}^{-1}$ for 1 MHz. The presented study could highlight the usage of Au/Pyrene-imine/n-Si Schottky diode in organic electronic applications.

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