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Fabrication and electrical characterization of the surface-type Au/NiPc/Ag diode

M. SHAH[a*], M. H. SAYYAD[a], KH. S. KARIMOV[a, b], M. MAHROOF-TAHIR[c]
[a]*Ghulam Ishaq Khan Institute of Engineering Sciences and Technology, Topi*-23640*, District Swabi, NWFP, Pakistan*
[b]*Physical Technical Institute of Academy of Sciences, Rudaki Ave.33, Dushanbe, 734025, Tajikistan*
[c]*St.Cloud State University , 720 Fourth Avenue South St.Cloud, MN 56301-4498, USA*

This paper reports on the fabrication and investigation of nickel phthalocyanine (NiPc) thin film based surface-type device. In this device thin film of NiPc of thickness 170 nm is thermally sublimed on glass substrate with preliminary deposited silver and gold electrodes to form the surface-type Au/NiPc/Ag Schottky diode. The dark current-voltage characteristics are investigated at room temperature. The barrier height is calculated from the I-V curve and is found equal to 1.11eV. The value of mobility and conductivity is calculated as $9.3\times10^{-9} cm^2V^{-1}S^{-1}$ and $3.42\times10^{-7}\Omega^{-1}cm^{-1}$, respectively. It is observed that at low voltages the device shows ohmic conduction and at higher voltages the conduction mechanisms are dominated by space charge limited current.

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1. Introduction

Organic semiconductor have been investigated due to their use in a variety of electronic and optoelectronic devices, such as, photocapacitors [1,2], solar cells [3,4], organic light emitting diodes[5] and humidity sensors [6]. The organic semiconductor based devices attract much attention due to light weight, low cost, large area, deposition on flexible substrates and ease to device fabrication.

Phthalocyanines (PCs) are a particular class of organic semiconductors exhibiting interesting electrical and optical properties [7]. These materials are thermally stable and do not decompose on sublimation, therefore, thin films of phthalocyanines can be prepared by thermal evaporation [8, 9]. These organic semiconductor compounds usually absorb light in the visible region of the spectrum [7]. The electrical, optical and structural properties of phthalocyanine thin films are dependent on various parameters such as evaporation rate, substrate temperature and post-deposition annealing [10-12].

It was reported that metal phthalocyanine make Schottky junction with suitable metallic electrodes [13-16]. Nickel phthalocyanine as an active material was deposited between the gold and lead electrodes [17]. It was found that the current-voltage characteristics show an ohmic conduction in lower voltage followed by space-charge-limited current at higher voltage [17]. M. M. El-Nahass *et al* fabricated multilayer sandwich structure of Al/NiPc/Au and investigated the effect of annealing at 623K for 2h on the electrical properties of the device [18]. The rectification ratio of the device was increased from 4.8 to 124 at ± 1 V after annealing.

Most of these devices are usually fabricated in sandwich configuration and this structure requires the deposition of organic thin films on transparent conductive electrodes using vacuum evaporator or spin coater. On top of these films, metallic electrodes are deposited, which often damage the active material. Surface type organic thin film structures represent a simple, low cost and versatile alternative to the devices built in sandwich configuration. Because of these advantages, there is a growing interest in the fabrication and study of surface type optoelectronic devices employing organic semiconductors [19-21]. Also the surface type devices are very suitable for exploring the low cost and simple device fabrication techniques, such as spin or drop-coating, screen printing, inkjet printing etc.

In this work, we have fabricated and investigated the electrical characteristics of the surface-type Ag/NiPc/Au diode.

2. Experimental

The NiPc powder was obtained from Sigma Aldrich and used as base material in the present study. To fabricate surface-type diode, metallic electrodes of gold and silver of 100nm film thickness was deposited by thermal vacuum evaporation technique on thoroughly cleaned glass substrates. Then thin film of NiPc was thermally sublimed on glass substrate with preliminary deposited metallic electrodes. All the films were deposited at deposition rates of 0.2nm/s. During the deposition the pressure in vacuum chamber was kept constant at about 10^{-5} mbar. The thickness of each layer and the deposition rates were monitored by a crystal-controlled thickness monitor [22]. The surface- type structure Au/NiPc/Ag was fabricated.

Fig. 1 shows the cross-sectional view of the device used in this work. To characterize the organic diodes, the current voltage characteristics were measured by using MDC CSM/Win System-Quiet CHUCK. All the measurements were taken under dark condition at room temperature. Currents were measured for the different values of applied voltages ranging from -15 to 20 V for the surface-type Ag/NiPc/Au diode.

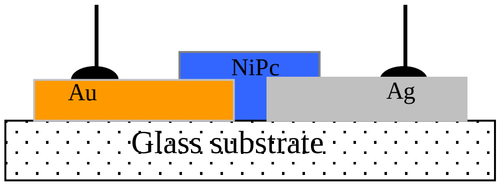

Fig. 1. Cross sectional view of the Au/NiPc/Ag.

3. Results and discussion

The measured current-voltage characteristics of Au/NiPc/Ag Schottky diodes under dark condition are plotted in Fig. 2. The current of the device increased exponentially in the forward bias and in the reverse bias the current was found to increase slowly with the increasing of voltage. It is clear from the Fig. 2 that the I-V curve is non linear and asymmetric shows that the device exhibit rectification behavior. The rectification ratio is 3 at ±14V. The rectification is due to the formation of rectifying barrier at the metal/organic semiconductor interface.

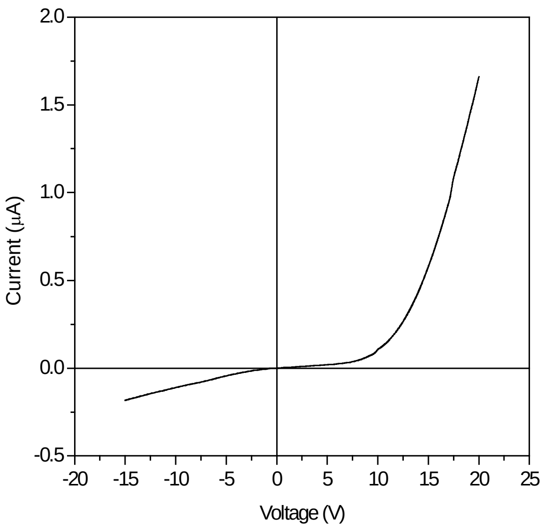

Fig. 2. Current-voltage characteristics of the Au/NiPc/Ag diode.

For analysis of dark current the modified Shockley equation may be expressed as [23]

$$I = I_o\left[Exp\frac{q(V-IR_s)}{nkT}-1\right]+\frac{(V-IR_s)}{R_{sh}} \tag{1}$$

where I and V are the terminal current and voltage, I_o is the saturation current, n is ideality factor, k is Boltzmann's constant, and Rs and Rsh are the series and shunt resistances, respectively.

The semi logarithmic plot of the Ag/NiPc/Au is shown in Fig. 3. From these intersection of forward bias curve with vertical axes reverse saturation current was determined, $I_o = 2.43 \times 10^{-9}$ A. The value of barrier height φ is calculated from the expression of reverse saturation current

$$I_o = A^*T^2\exp(-\varphi q/KT) \tag{2}$$

where A is Richardson constant and its value is $1.3\times10^5\ A/m^2K^2$ for NiPc [24]. The value of barrier height is calculated as 1.11 eV. The barrier height calculated for the sandwich-type Au/NiPc/Pb Schottky diode is 1.07 eV reported in [24].

Fig. 4 shows the experimental results of junction resistance R_J, versus voltage for the surface-type Au/NiPc/Ag diode. It was observed from Fig.4 that, the junction resistance at sufficiently high forward bias approaches a minimum value, which is series resistance, Rs. On the other hand, at sufficiently high reverse bias, the junction resistance has a maximum value, which is called shunt resistance. The series resistance Rs =12 MΩ and shunt resistance R_sh =280 MΩ were calculated from the plot of diode resistance. The value of junction resistance can be determined by $R_J = \partial V/\partial I$ from the current-voltage characteristic of the diode.

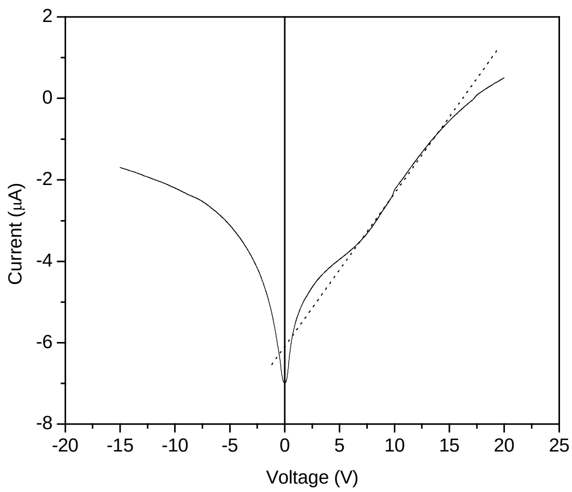

Fig. 3. Semi logarithmic plot of the current-voltage curve.

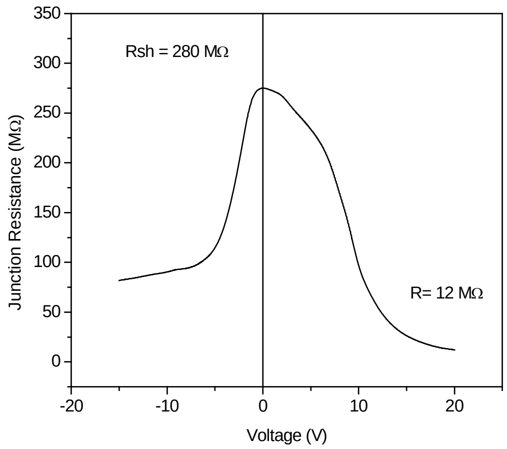

Fig. 4. Junction resistance, R_J, versus V for Au/NiPc/Ag.

Fig. 5 shows the logI vs. logV plot of Schottky diode in forward bias voltage. It was observed from the Fig. 5 that under forward biases Schottky diode shows three distinct regions: ohmic, space charge limited current (SCL) and trap SCL regimes [22, 25]. In the low voltage range the slope of the graph is in the order of unity and hence taken as an ohmic conduction between the organic layer and the electrodes. The current density J within the ohmic region was described by the following equation [26]:

$$J = en_o\mu\frac{V}{d} \tag{3}$$

where V is the applied voltage, e is the electronic charge, d the gap between the electrodes, μ the carrier mobility and n_o the free carrier density.

The slope of region II is about 2 and the current varies with voltage as I ~V^2 similar to SCLC followed by a third region III of I~$V^{3.6}$. Such power dependence leads to conclusion that the conduction mechanism is due to SCLC dominated by a discrete trapping level in region II and by exponential distribution in region III. The different slopes at the different regions of I-V curve are due to traps band with different energies. The hopping model is used to justify the transport mechanism through the organic materials by localized energy states which are arises due to lack of order, impurities and dislocation etc. Theses localized states are uniformly distributed within the energy band gap. The current density J in the presence of shallow traps in the organic films is expressed by [27]:

$$J = \frac{9\varepsilon_s\theta\mu V^2}{8d^3} \tag{4}$$

where ε_s is the permittivity of the organic semiconductor, μ is the charge carrier mobility, and d is the gape between electrodes, V is the applied voltage and θ is the trap factor. The equation for the trap factor is written as [28].

$$\theta = \frac{p_o}{P_o + P_t} \tag{5}$$

where p_o the density of is free carrier and p_t is the density of trapped hole and may be calculated as:

$$\theta = \frac{J_1}{J_2} \tag{6}$$

The value of trap factor can be determined by using Eq. (6), where J_1 and J_2 is the ratio of current densities at the beginning and at the end of square law region. The value of θ is calculated from the log-log graph of current voltage characteristics and is equal to 0.25.

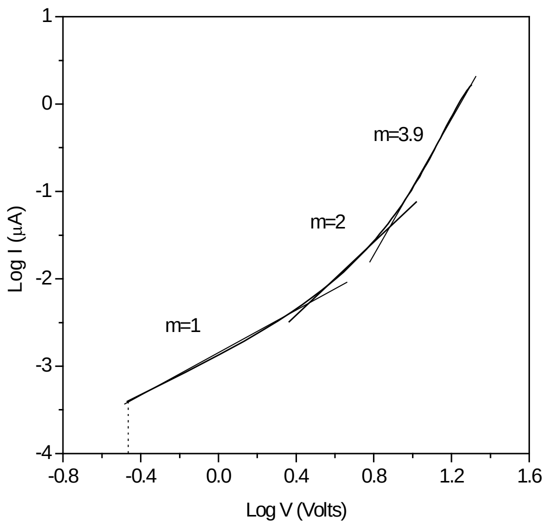

Fig. 5. Measured I-V curve for Au/NiPc/Ag in log-log representation.

The conductivity at room temperature in a linear region of current voltage characteristics can be calculated as:

$$\sigma = \frac{Jd}{V} \tag{7}$$

where, V is the applied voltage, J is current density and d is the gape between the electrodes. The value of conductivity is equal to $3.42\times10^{-7}\,\Omega^{-1}cm^{-1}$. This value is comparable with the value of conductivity $1.2\times10^{-8}\Omega^{-1}cm^{-1}$ for CuPc films [29].

The value of mobility can be determined by using Eq. (4) and is equal to $9.3\times10^{-9}cm^2V^{-1}S^{-1}$. The value of mobility obtained in this work compared with the value of mobility $1.21\times10^{-9}cm^2V^{-1}S^{-1}$ obtained for Au/NiPc/Al [30].

4. Conclusions

In this paper electrical characteristics of the surface-type Au/NiPc/Ag diode have been investigated. It was observed that at higher forward voltages the conduction mechanisms were dominated by space charged limited conduction (SCLC) controlled by a single and an exponential trapping levels at two different ranges of applied voltages. The mobility and conductivity were calculated from the current-voltage characteristics.

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*Corresponding author: mutabarshah@gmail.com