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Modification of Interfacial Properties of Organic Device in Presence of Single Walled Carbon Nanotubes

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ABSTRACT

Device performance gets significantly affected by the interfacial properties of the device. In this work, Schottky barrier and width of space – charge region have been estimated without and with SWCNT. Rose Bengal dye has been sandwiched in between Indium Tin Oxide (ITO) coated glass substrate and Aluminium. Schottky barrier is estimated by perusing steady state current – voltage plot. Image barrier lowering effect has also been considered to calculate the effective barrier in presence of externally applied electric field. Space- charge region width is interrelated to the both Schottky barrier and the applied electric field. It can be inferred that by incorporating SWCNT, schottky barrier and space- charge region width get reduced which will improve the current flow. Current flow improvement in presence of SWCNT can also be ascribed to the lowering of energy of traps which has also been determined in this work.

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Introduction

Organic semiconductors have certain features such as low manufacturing cost, ease of processing, energy efficiency and eco- friendly properties and these features are very attractive to use them as manufacturing materials for different electronic devices [1-3] albeit there are certain impediments also which need to be considered. Some major constraints are high schottky barrier and high space – charge layer width at metal – organic contact. The intermolecular interaction of organic semiconductors consists of weak Van der Walls forces [4-6]. The gap states of organic materials cause charge carrier trapping and thus charge trapping becomes a ubiquitous phenomenon that severely impacts the organic semiconductor based device performance. Density of States (DOS) that signifies a localized electronic state within the organic semiconductor is well known as trap DOS [7-8]. In present work, traps are described using Gaussian function. Traps can be classified as shallow traps and deep traps [9]. Shallow traps are located at a distance of a few kT from the edges of band, whereas the deep traps are located at a distance of a further kT from the edges of band [10].

In present work, Rose Bengal Dye as an organic material will be sandwiched in between ITO and Aluminium. Electrical characterization of device is done to analyze the charge carrier trapping effect, interfacial injection barrier considering the image barrier lowering effect and depletion layer width. We have characterized the device by using the model developed by H. Bässler and Richardson Schottky thermionic emission. Incorporation of SWCNT has also been done to study the modification it does to these interfacial parameters.

Experimental

Materials and Sample Preparation

Figures 1(a) and 1(b) show schematic of RB dye and SWCNT respectively. RB dye and SWCNT were procured from Loba Chemie Private Ltd, India and SRL, India respectively. RB dye can be used as a biological stain [11]. ITO coated glass and aluminium are used as front electrode and back electrode respectively.

We have used Poly Vinyl Alcohol (PVA) which is used as transparent inert binder. Details of the making of PVA solution are mentioned in one of our previously published works [12]. RB dye solution is formed by adding 1 mg of RB dye with the prepared PVA solution. After that this RB dye solution is segregated and it is kept in two beakers. In one beaker, there is only RB dye solution and in another beaker, 1 mg SWCNT is prepended to form the solution with SWCNT and this solution is stirred for one hour.

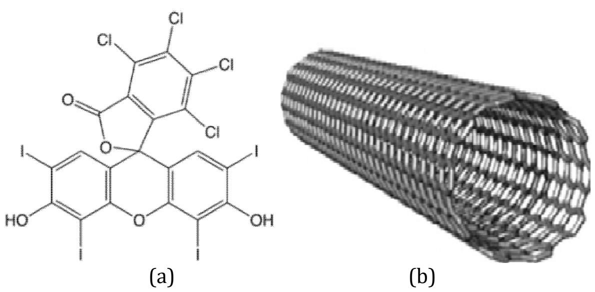

Figure 1: Schematic of (a) RB dye, and (b) SWCNT

Now, both solutions, with and without SWCNT respectively, are spin coated on ITO and Al electrodes and when the electrodes are in moderately dry state, they are intercalated together to prepare device. Figure 2 illustrates the prepared device.

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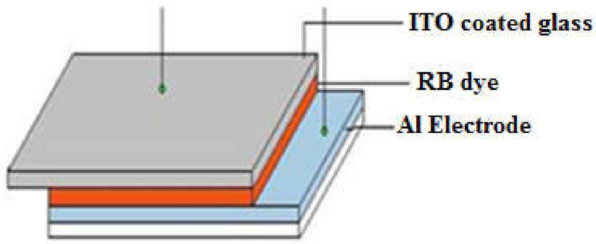

Figure 2: Diagrammatical representation of RB dye based organic device

Measurements

Current-voltage (I-V) plots of prepared device have been estimated using Keithley 2400 source measure unit. Details of measurement technique are akin to measurement section of one of our previously published works [13].

Results and Discussion

Charge flow can be described by using Richardson Schottky model, as depicted in the following equations (1- 4)

$$I = AA^*T^2 \exp\left(-\frac{q\phi_b}{kT}\right)\left(\exp\left(\frac{qV}{nkT}\right) - 1\right) \qquad (1)$$

The above equation (1) can also be rewritten as

$$I = I_0\left(\exp\left(\frac{qV}{nkT}\right) - 1\right) \qquad (2)$$

Where I_0 is given in following equation (3)

$$I_0 = AA^*T^2 \exp\left(-\frac{q\phi_b}{kT}\right) \qquad (3)$$

The height of schottky barrier can be determined from the above equation (3)

$$\phi_b = \frac{kT}{q}\ln\left(\frac{AA^*T^2}{I_0}\right) \qquad (4)$$

All notations mentioned above have their usual meaning [14-18].

Figure 3 illustrates dark I-V plots in presence and absence of SWCNT. It can be said from Fig. 3, that by incorporating SWCNT, the current flow increases significantly.

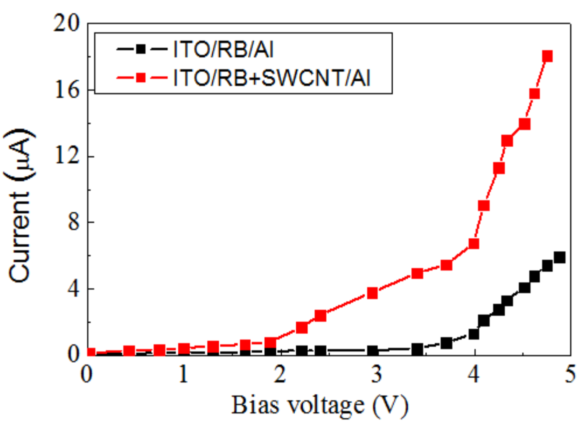

Figure 3: Dark I-V plot with and without SWCNT

Threshold voltage V_{th} can be estimated from the following equation (5)

$$V_{th}^m = H_n^m.B \qquad (5)$$

Where, $m = \frac{T_C}{T}$, which defines trap distribution and also

$$A = (qL^2/\varepsilon)^m \text{ and } B = A.\frac{(m+1)^{(2m+1)}}{m^m(2m+1)^{(m+1)}}$$

The trap energy E_t can also be estimated from the following equation (6)

$$E_t = mkT \qquad (6)$$

It can be deduced that the trap energy lessens from 0.087 eV to 0.054 eV in presence of SWCNT.

Figure 4 shows semi logarithmic I-V plots without and with SWCNT respectively. Using equation (4), schottky barrier is estimated as 0.92 eV without SWCNT and it lessens to 0.83 eV with SWCNT.

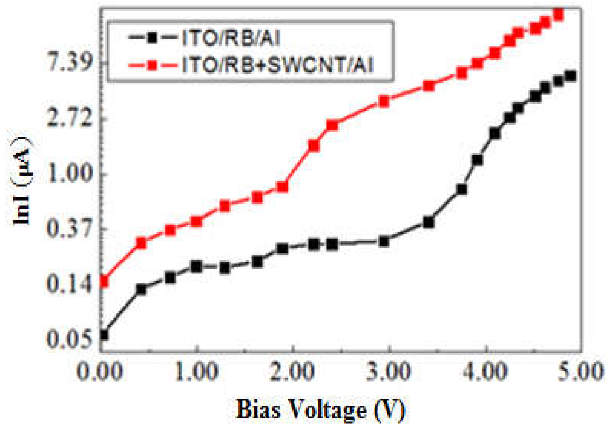

Figure 4: Semilogarithmic I- V plot with and without SWCNT

In this present paper, barrier lowering due to image charges is also considered. Current injection is limited by barrier potential U(x) which can be enunciated as addition of external electric field and the Coulomb field [19], which is written in the following expression (7)

$$U(x) = \phi_b - \frac{e^2}{16\pi\varepsilon_0\varepsilon x} - eFx \qquad (7)$$

x = distance of potential distribution from the metal – organic interface with all other notations have their usual meaning.

The value of dielectric constant is considered to be 3.5 and the distribution of potential is at 3 nm from the interface. Electric field is varied from 10^6 V/cm to 2×10^6 V/cm and the dependence of effective schottky barrier on the applied electric field of RB dye based device with and without SWCNT has been depicted in Fig. 5. Figure 5 shows that the effective barrier height almost linearly decreases with increasing applied field in organic device.

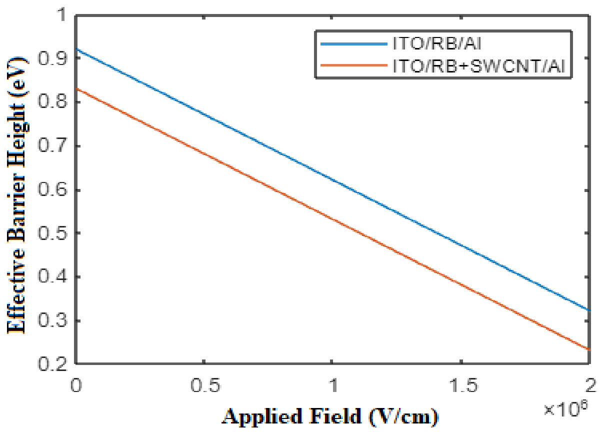

Figure 5: Dependence of Effective Schottky Barrier on the Applied Field

The dependence of effective barrier height on the distance from interfacial contact of RB dye based device with and without SWCNT has also been illustrated in Fig. 6. Figure 6 illustrates that as distance from metal – organic dye interface increases, the effective barrier height decreases.

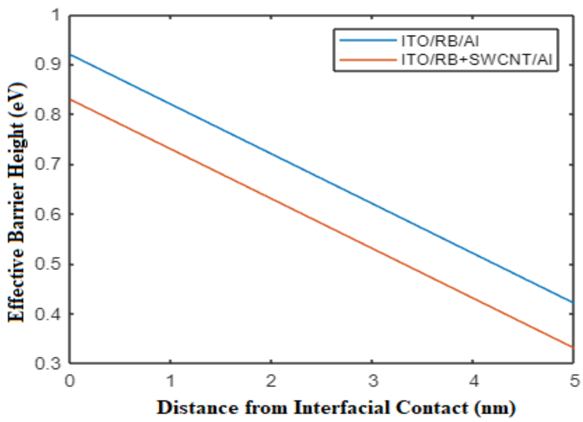

Figure 6: Dependence of Effective Barrier Height on the Distance from Interfacial Contact of RB dye based device with and without SWCNT

The space - charge layer width can be estimated from following equation (8)

$$W_d = \sqrt{\frac{2\varepsilon_0 \varepsilon_s V_d}{qN_D}} \quad (8)$$

W_d= space - charge layer width, ε_0= vacuum permittivity, ε_s= semiconductor permittivity, V_d= diffusion potential, q= charge of an electron, N_D= donor atom concentration.

The depletion layer width can also be related to the barrier height by using the following equation (9)

$$W_d = \frac{\phi_b}{F} \quad (9)$$

Figure 7 shows the interdependence of space - charge layer width with the applied electric field. It can be easily inferred that with increasing applied electric field, the interfacial depletion layer width has been lowered.

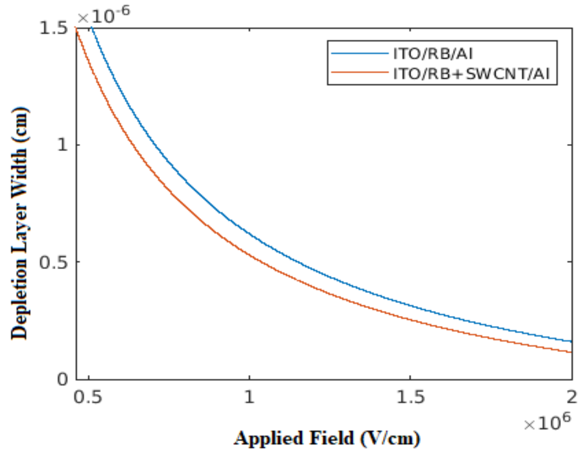

Figure 7: Dependence of Depletion Layer Width on the Applied Field

In Fig. 8, the relationship between the effective schottky barrier and space - charge layer width has been depicted. It has been observed that space - charge layer width is directly proportional to the effective schottky barrier which means space - charge layer width escalates with rising value of effective schottky barrier.

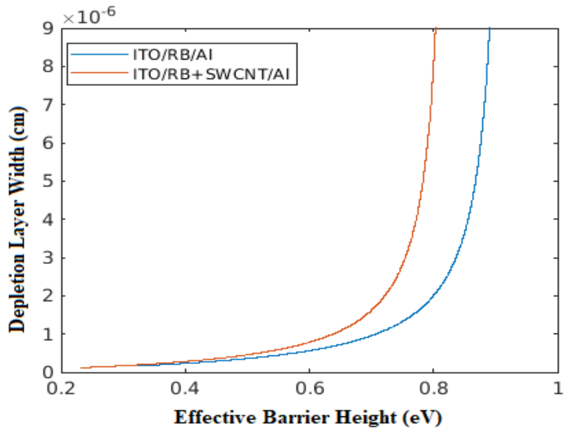

Figure 8: Dependence of Depletion Layer Width on the Effective Schottky Barrier

The value of trap energy, schottky barrier and space - charge layer width with and without SWCNT has been expressed in the Table 1. The space - charge layer width and image barrier lowering effect have been calculated considering the value of electric field is 10^6 V/cm.

Table 1: Estimation of trap energy, schottky barrier, image barrier lowering effect on schottky barrier and space - charge layer width

Dye	Trap Energy (eV)	Schottky Barrier from I-V Plot (eV)	Effective Schottky Barrier Considering Image Charges (eV)	Space- Charge Layer Width (W_d) (cm) (F = 10^6 V/cm)
RB	0.087	0.920	0.754	9.10×10^{-6}
RB+SWCNT	0.054	0.830	0.643	7.27×10^{-6}

Conclusions

The effect of SWCNT on charge trapping effect, schottky barrier and space - charge layer width of RB dye based organic device has been studied. Schottky barrier is calculated from I-V plots of device. It is observed that, with SWCNT, the schottky barrier and space - charge layer width are reduced. Image barrier lowering effect has also been estimated with and without SWCNT. Lessening values of schottky barrier and space - charge layer width improve the charge injection. Charge injection improvement can be attributed to trap energy lowering due to the presence of SWCNT, which has also been estimated in this work. The interdependence of the schottky barrier and space - charge layer width in the presence of externally applied electric field has also been depicted.

Conflict of Interest

As the corresponding author of this paper, on behalf of myself and all other co authors, I state that there is no conflict of interest.

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