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Modification of Trap Energy and Barrier Height in Crystal Violet (CV) Dye based Organic Device in Presence of Single Walled Carbon Nanotubes (SWCNT)

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ABSTRACT

In this work, we have estimated the trap energy (E_t) and barrier height (ϕ_b) of ITO coated glass/Crystal Violet (CV) dye /Aluminium (Al) based organic device and subsequently we have also observed the effect of SWCNT on both these parameters E_t and ϕ_b. Presence of SWCNT reduces both the trap energy and barrier height as SWCNT acts as filler and provides easy path for charge percolation. We have used ITO coated glass as front electrode and aluminium as back electrode to form the organic device. This organic device has been prepared with and without SWCNT by using spin coating technique. We have measured the steady state current-voltage (I-V) characteristics of the device to estimate the trap energy (E_t) and barrier height (ϕ_b) of the device. E_t is reduced from 0.085 eV to 0.065 eV and ϕ_b is reduced from 0.87 eV to 0.79 eV in the presence of SWCNT. Reduction of the trap energy and barrier height in presence of SWCNT indicates the enhancement of charge injection through the metal - organic dye interface. By suitable doping or addition of SWCNT within the CV dye it is possible to modify the trap energy and thereby to reduce the barrier height and enhance the current injection through metal-organic dye interface.

Keywords: *Barrier Height, Crystal Violet Dye, Metal-organic dye interface, SWCNT, Trap Energy.*

1. INTRODUCTION

Recently the organic/polymer materials are being widely investigated to develop different electronic and optoelectronic devices. Organic devices are more flexible, light weight, cost effective and can be easily fabricated over a large area. Despite these advantages, there are also certain limitations of organic devices. One of the limitations is organic devices are prone to traps which leads to high barrier height (φ_b) at metal-organic layer interface [1]. Due to high barrier height, the charge injection from metal to organic layer is low. There is not much study on the dependence of barrier height on trap energy of organic devices at the metal-organic layer interface. Attempts need to be made to reduce the trap energy to improve the charge injection at the interface of metal-organic layer and thereby to reduce the barrier height. [2].The injection of charges at the metal-organic layer interface has significant influence on the electrical properties of these organic devices and creates more impact than charge transport within the organic devices. To reduce the trap energy at the metal-organic layer interface, we have incorporated SWCNT within the device. Presence of SWCNT decreases the trap energy at the metal-organic semiconductor interface and thereby reduces the barrier height. Reduction of interfacial barrier height will lead to better injection of charges at the interface and thus will provide better conductivity [3].

The charge injection barrier at the interface between a metal and organic material is commonly described by the interfacial barrier of metal to semiconductor contact. Basically the barrier height is caused by the difference between the fermi energy level of metal and the energy band of organic material. Injection current usually consists of thermionic-injection current and field-induced tunneling current. In this paper, we have used Richardson – Schottky (RS) model of thermionic emission to characterize the organic device [4].

2. MATERIALS AND SAMPLE PREPARATION

Fig. 1(a) shows CV dye which is procured from Loba Chemie Private Ltd, India. CV dye with chemical formula [$C_{25}N_3H_{30}Cl$] is a cationic dye that dissociates in aqueous solution to give a positively charged coloured ion [5]. CV dye can be used as optical active material Fig. 1(b) shows SWCNT which was obtained from SRL, India. ITO coated glass is used as front electrode whereas aluminium (Al) is used as the back electrode of the organic device.

(a) (b)

Fig. 1 Structural diagram of (a) Crystal Violet (CV), and (b) Single Walled Carbon Nanotubes (SWCNT)

Poly vinyl alcohol (PVA) solution is obtained by mixing 1 gm of PVA and 10 ml of distilled water. 1 mg of CV dye is added with this solution and stirred well for around 30 min. A part of this dye solution is separated in a beaker and to it 1 mg of SWCNT is added and stirred for one hour. Now, both the solutions, with and without SWCNT, are spin coated on ITO and Al electrodes at a speed of 1500 rpm and then dried at a speed of 3500 rpm. When the electrodes reach semi-dry state, they are sandwiched together to form the devices. In order to check the reproducibility of the measurement, different devices are prepared and kept under vacuum for 12 hours before characterization. The schematic diagram of the device is shown in Fig. 2.

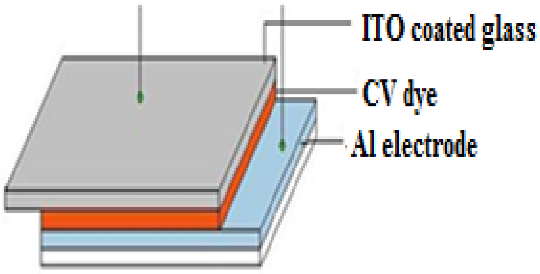


Fig. 2 Schematic diagram of the organic device

3. MEASUREMENTS

Dark current-voltage (I-V) characteristics of the cells have been measured with a Keithley 2400 source measure unit. For dark I-V measurement, the front electrode is connected to the positive terminal of the battery and the negative terminal of the battery is connected to back electrode of the device. During measurement, the bias voltage is varied from 0 to 6 volt in steps of 0.5 volt with 1000 ms delay. The experiments have been done in the clean open atmosphere of the laboratory at a room temperature of 26 °C.

4. RESULTS AND DISCUSSIONS

The current through a metal-organic semiconductor interface due to thermionic emission can be expressed as:

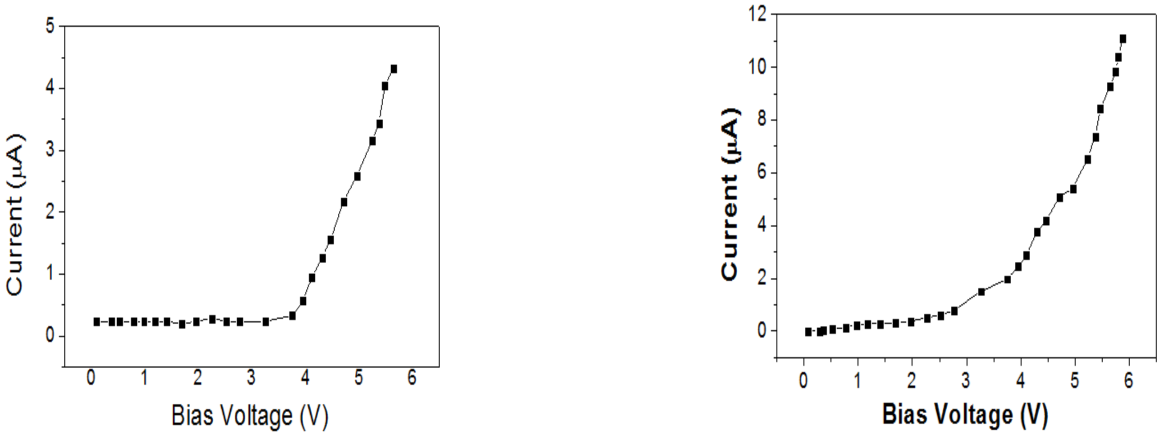
$$I = I_0 \left[\exp\left(\frac{qV}{nkT}\right) - 1\right] \qquad (1)$$

Where I_0 is the saturation current, which is given by :

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

Here, q is the electronic charge, V is the applied voltage, A is the area of the device, k is the Boltzmann's constant, T is the absolute temperature, A* is the effective Richardson constant of $120 Am^{-2}K^{-2}$ for Crystal Violet dye, ϕ_b is the interfacial barrier height and n is the ideality factor [6].

The dark I-V characteristics of CV dye based organic device in absence and presence of SWCNT are shown in Fig. 3 (a) and 3 (b) respectively. The value of dark current is quite low for the CV dye under experiment. But current increases when SWCNTs are incorporated with this CV dye based organic device.



(a) (b)

Fig.3 Dark I-V characteristics of organic device comprising of CV dye (a) without SWCNT and (b) with SWCNT

Solving the I-V relation the transition voltage V_{th} is expressed as given in equation (3)

$$V_{th}^{m} = H_{n}^{m}.B \qquad (3)$$

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

From the results it can be seen that in presence of SWCNT the 'm' value reduces. And consequently the trap energy E_t also reduces where $m= (E_t/kT)$ [7]. It has been found out that the trap energy reduces from 0.085 eV to 0.065 eV in presence of SWCNT.

Interfacial Barrier Height of metal - organic semiconductor device can be determined from the following relation [8] – [10]

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

Fig. 4 shows semi logarithmic I-V curves of CV dye based organic device in absence and presence of SWCNT respectively. The reverse saturation current I_0 is determined from the y-intercept of both the semi logarithmic I-V curves. Applying equation (4), the barrier height of CV dye based organic device is calculated which is 0.87 eV in absence of SWCNT and the value of barrier height reduces to 0.79 eV in presence of SWCNT.

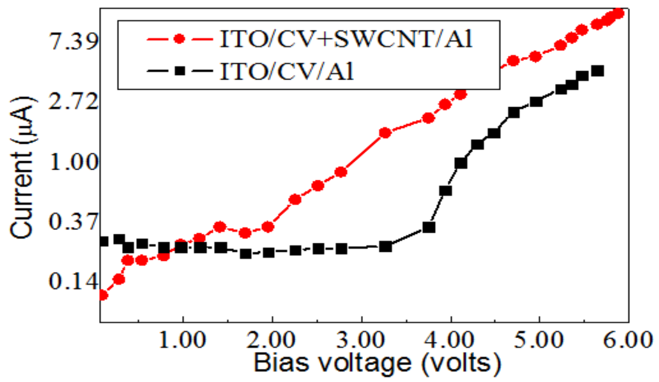


Fig.4 ln I -V characteristics of CV dye based device with and without SWCNT

Table 1 Calculation of trap energy and barrier height of CV dye based organic devices in absence and presence of SWCNT

Dye used		Trap energy E_t (eV)	Barrier Height ϕ_b (eV)
Crystal Violet (CV)	Without SWCNT	0.085	0.87
	With SWCNT	0.065	0.79

5. CONCLUSIONS

In this paper, we have studied the effect of SWCNT on the interfacial barrier height and trap energy of CV dye based organic device. Values of barrier height and trap energy for CV dye based organic device are calculated by analyzing I-V characteristics of the device. It is observed that in presence of single walled carbon nanotube the trap energy at the metal - organic layer interface is reduced. Reduction of trap energy improves the charge injection which results in higher conductivity. Incorporation of SWCNT also reduces the barrier height of the device which can be attributed to the reduction of trap energy at the metal – organic layer interface.

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REFERENCES

[1] Sungyeop Jung, Chang-Hyun Kim, Yvan Bonnassieux and Gilles Horowitz, "Injection barrier at metal/organic semiconductor junctions with a Gaussian density-of-states," *J. Phys. D: Appl. Phys, vol. 48, no.395103*, 2015

[2] Akichika Kumatani, Yun Li, Kazuhito Tsukagoshi "On Practical Charge Injection at the Metal/Organic Semiconductor Interface," *Nature, vol. 3, no.1026*, 2013

[3] Z. Harrabi, S. Jomni, L. Beji and A. Bouazizi, "Distribution of barrier heights in Au/porous GaAs Schottky diodes from current–voltage–temperature measurements," *Physica B, vol. 405, no. 3745*, 2010

[4] S.M.Sze, Kwok K. NG, Physics of Semiconductor Devices. *Wiley & Sóns*, 2007

[5] S. Chakraborty, N.B.Manik, "Effect of single walled carbon nanotubes on the threshold voltage of dye based photovoltaic devices," *Physica B, vol. 481, no. 209,* 2016

[6] K.Chakraborty, S. Chakraborty, N.B.Manik, "Effect of singlewalled carbon nanotubes on series resistance of Rose Bengal and Methyl Red dye-based organic photovoltaic device,"*J.Semicond, vol. 39, no. 094001*, 2018

[7] S. Chakraborty, N.B.Manik, "Effect of COOH-functionalized SWCNT addition on the electrical and photovoltaic characteristics of Malachite Green dye based photovoltaic cells," *J. Semicond*, vol. 35, no. 12, 2014

[8] Z. Ahmad, M. H. Sayyad, "Electrical characteristics of a high rectification ratio organic schottky diode based on Methyl red," *Optoelectron Adv Mater Optoelectronics And Advanced Materials – Rapid Communications, vol. 3, no. 5,* 2009

[9] Nico Armbrust, Frederik Schiller, Jens Güdde & Ulrich Höfer, "Model potential for the description of metal/organic interface states," *Nature, vol.7, no. 46561,* 2017

[10] F.Yakuphnoglu, M.Shah, A.W.Farooq, "Electrical and Interfacial Properties of p- Si/P3HT Organic Junction Barrier," *Acta Physica Polonica A, vol.120, no. 558,* 2011