RESEARCH ARTICLE

Study on the Effect of 8 nm Size Multi Walled Carbon Nanotubes (MWCNT) on the Barrier Height of Malachite Green (MG) Dye Based Organic Device

Sudipta Sen*, Nabin Baran Manik

Condensed Matter Physics Research Centre, Department of Physics, Jadavpur University, Kolkata - 700032, India.

ABSTRACT: In this paper, we have studied the effect of 8 nm sized multi walled carbon nanotubes (MWCNT) on the barrier height (ϕ_b) of ITO coated glass/Malachite Green (MG) dye /Aluminium (Al) based organic device. Presence of 8 nm MWCNT reduces the metal-organic interfacial barrier height as it enhances the charge separation and relaxation process. 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 MWCNT by using spin coating technique. We have measured the steady state current-voltage (I-V) characteristics of the device to estimate the V_{th} and barrier height (ϕ_b) of the device. In the presence of 8 nm MWCNT, V_{th} is reduced from 3.9 V to 2.37 V and ϕ_b is reduced from 1.12 eV to 0.97 eV. Reduction of the threshold voltage and barrier height in the presence of MWCNT indicates the enhancement of charge injection through the metal- organic dye interface. By suitable doping or addition of MWCNT within the MG dye it is possible to modify the barrier height and thereby to control the threshold voltage and the conductivity.

KEYWORDS: Malachite Green Dye; Threshold Voltage; Barrier Height; 8 nm MWCNT

https://doi.org/10.29294/IJASE.6.S2.2020.23-27

1. INTRODUCTION

In these days, 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 major limitations is the high barrier height (ϕ_b) at metal-organic layer interface. Due to high interfacial barrier height, the charge injection from metal to organic layer is low which attributes to higher threshold voltage (V_{th}). There is not much study on the barrier height particularly at below threshold voltage (V_{th}) of organic devices at the metal-organic layer interface. Attempts need to be made to reduce the barrier height to improve the charge injection at the interface of metal-organic layer and thereby to reduce the threshold voltage. At the below threshold voltage regime, the charge injection process is strongly dependent on the barrier height at the metal- organic layer interface [1-2]. Barrier height at the metal-organic semiconductor interface is an important parameter for the injection of charge carriers at the low voltage or below threshold voltage regime. The process of charge injection at the interface of metal and organic material has a significant impact on the electrical properties of organic devices. To reduce the barrier height at the metal-organic layer interface, we have incorporated 8 nm MWCNT within the device. MWCNT reduces the interfacial barrier height and the threshold voltage at the metal-organic semiconductor interface. Reduction of interfacial barrier height will lead to better injection of charges at the interface and thus will provide better conductivity [3].

Generally, the injection barrier height at the metal to organic interface is commonly described by the metal to semiconductor contact. Injection- limited current flow generally occurs at below threshold voltage region. Injection current generally consists of thermionic-injection current and field-induced tunnelling current. At the low voltage region, field induced tunnelling current is so small that it can be neglected. For this reason, Richardson – Schottky (RS) model of thermionic emission is used to characterize the device at low voltage region [4].

2. MATERIALS AND SAMPLE PREPARATION

MG dye and non functionalized MWCNT are purchased from Finer Chemicals, Ahmedabad and Sisco Research Laboratories, India respectively. MG dye is a triarylmethane dye. PolyMethyl Methacrylate (PMMA) is procured from Merck Specialties Pvt. Ltd, Mumbai. Here PMMA acts as an inert binder [5]. To fabricate the organic device, Indium Tin Oxide (ITO) coated glass is used as the front electrode and Aluminium (Al) is used as the back electrode. Fig. 1 (a) and Fig. 1 (b) show the structures of MG dye and MWCNT respectively.

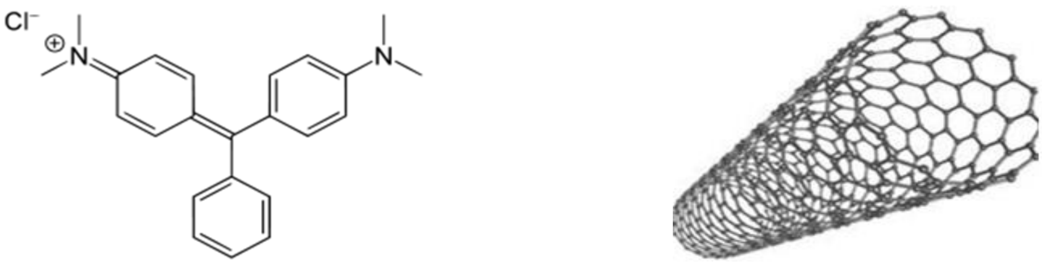
10 ml of double distilled water is taken in a clean test tube and in it 1g of PMMA is added to prepare the MG dye solution. To get a clear solution, the mixture is stirred with a magnetic stirrer for 30 min. In this solution, 1 mg of MG dye is added and stirred for 15 min. This solution is then divided into two parts in two pre-cleaned test tubes. In the test-tube MWCNT of size 8 nm are added respectively and stirred for 2 hours to get a homogeneous solution of dye and

**Corresponding Author: sagnike000@gmail.com*

Received: 20.10.2019 **Accepted:** 18.12.2019 **Published on**: 27.01.2020

MWCNT. The solubility of the solution is 100µg/ml.

To prepare the device, the 8 nm MWCNT added MG dye solution is taken and coated on a pre- cleaned ITO coated glass which is kept on a spin coater rotating at a speed of 1500 rpm and then dried at a speed of 3500 rpm. The same solution is spin coated on the Al back electrode. When both these electrodes are in semi-dry state, they are sandwiched together to form the 8 nm MWCNT cell. The cells are kept in vacuum for 12 hours to dry before using them for characterization. The schematic diagram of the device is shown in Fig. 2.



(a) (b)

Figure 1 Structures of (a) Malachite green dye and (b) Multi walled carbon nanotubes (MWCNT)

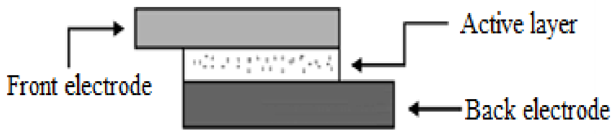


Figure 2 Schematic Diagram of the Organic Device

3. MEASUREMENTS

The dark current-voltage (I-V) characteristics of the organic devices without and with 8 nm MWCNT have been measured with a Keithley 2400 source measure unit. During measurement, the bias voltage is varied from 0 to 5 volts in steps of 0.5 volts with 1000 ms delay. The experiments are carried out in the clean open atmosphere of the laboratory at 27^{0}C temperature.

4. RESULTS AND DISCUSSIONS

The current at metal-organic interface due to thermionic emission can be expressed as

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

Where I_s is the saturation current, which can be expressed as

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

and

$$A^* = \frac{4\pi q m^* k^2}{h^3} \qquad (3)$$

Here, q is the electronic charge, V is the bias 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 120Am^{-2}K^{-2} for Malachite Green dye, ϕ_b is the interfacial barrier height and n is the ideality factor [6 - 9].

The barrier height at the metal- organic interface can be determined from the following relation [10 - 12]

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

The dark I-V characteristic of MG dye based organic device in absence of 8 nm MWCNT has been shown in Fig. 3.

The dark I-V characteristics of MG dye based device in presence of 8 nm MWCNT has been shown in Fig. 4. It has been found out that the current flow has been increased in presence of MWCNTs.

In Fig. 5, we have plotted the semilogarithmic plot of current-voltage characteristics of the ITO / MG / Al based organic device in absence of 8 nm MWCNT to calculate the barrier height.

We have also plotted the semilogarithmic plot of ITO / MG+8 nm MWCNT / Al based organic device which is shown in Fig. 6.

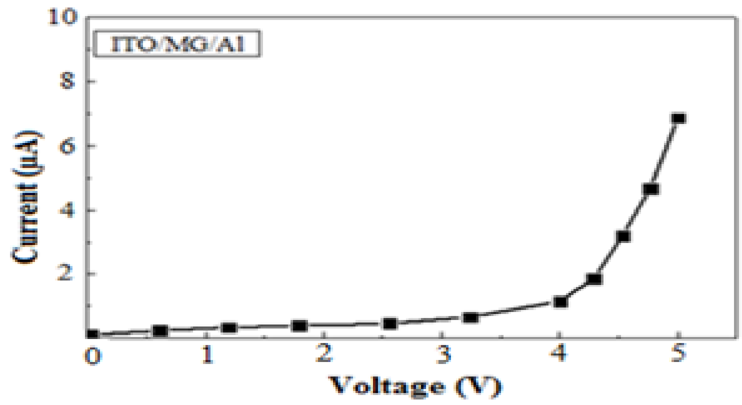


Fig . 3 Dark I-V characteristics of ITO/MG /Al based organic device in absence of 8 nm MWCNT

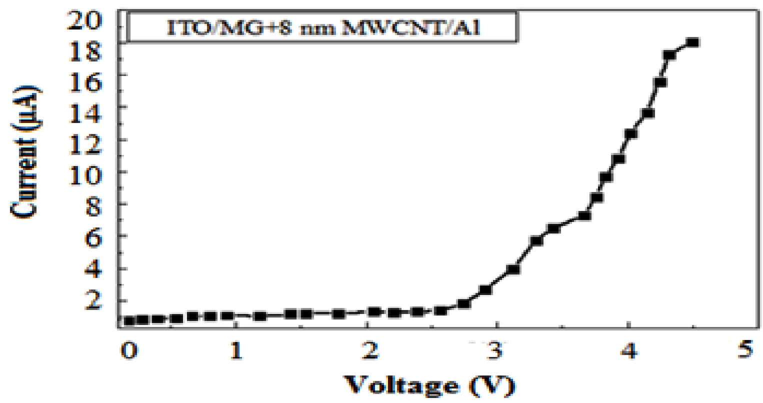


Fig . 4 Dark I-V characteristics of ITO/MG/Al based organic device in presence of 8 nm MWCNT

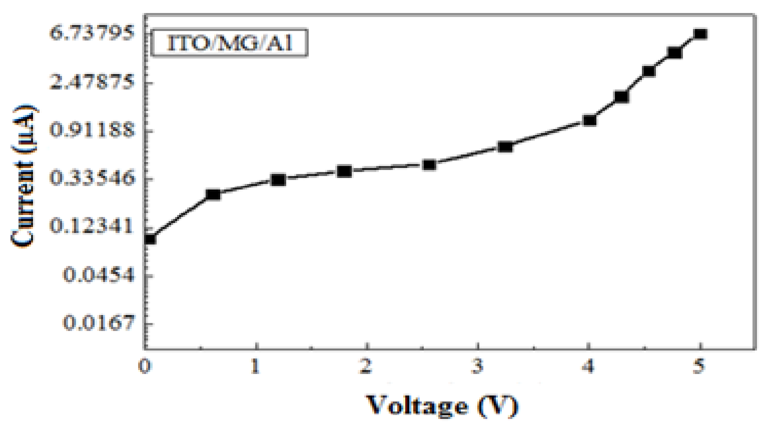


Fig. 5 Semi logarithmic plot of ITO/MG/Al based organic device in absence of 8 nm MWCNT

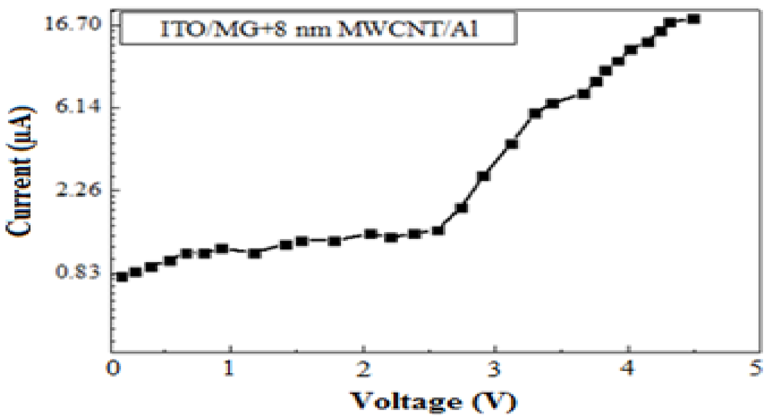


Fig. 6 Semi logarithmic plot of ITO / MG / Al based organic device in presence of 8 nm MWCNT

The calculation of threshold voltage and barrier height of MG dye based organic devices in absence and presence of 8 nm MWCNT is shown in Table 1.

Table 1 Calculation of threshold voltage and barrier height of MG dye based organic devices in absence and presence of 8 nm MWCNT

Device	Threshold voltage (in V)	Barrier height (in eV)
ITO / MG / Al	3.9	1.12
ITO / MG+8 nm MWCNT / Al	2.37	0.97

5. CONCLUSION

In this paper, we have studied the effect of 8 nm MWCNT on the interfacial barrier height of MG dye based organic device. Values of interfacial barrier height for MG dye based organic devices in absence and presence of MWCNTs are calculated using the plot of I-V characteristics of these devices. It can be said that in presence of multi walled carbon nanotubes, the injection barrier at the metal- organic layer interface has been reduced. Reduction of injection barrier improves the charge injection which results in better conductivity. Incorporation of MWCNT also reduces the threshold voltage of the device which can be attributed to reduction of interfacial injection barrier height. Due to their smaller sizes 8 nm MWCNT enhance the charge separation and relaxation process. This reduces the charge recombination and enhances current conduction through the system. This would result in increase of charge recombination and affect the performance of the device.

ACKNOWLEDGEMENTS

The author sincerely acknowledges University Grants Commission (UGC), India for financial assistance and one of the authors, Sudipta Sen is thankful to UGC for awarding a research fellowship.

REFERENCES

[1]. Scott J. C., 2003. Metal–organic interface and charge injection in organic electronic devices. Journal of Vacuum Science & Technology A, 21, 521-531.

[2]. Sze S. M., Ng Kwok K., 2007. Physics of Semiconductor Devices, third ed. Wiley & Sóns, New York, pp. 160-170.

[3]. Jung S., Kim C. H., Bonnassieux Y., Horowitz G., 2015. Injection barrier at metal/organic semiconductor junctions with a Gaussian density-of-states. Journal of Physics D: Applied Physics, 48, 395103-1-10.

[4]. Güllü Ö., 2016. Barrier Modification by Methyl Violet Organic Dye Molecules of Ag/P-Inp Structures. European Journal of Interdisciplinary Studies, 2, 7-17.

[5]. Chakraborty S., Manik N. B., 2014. Effect of COOH-functionalized SWCNT addition on the electrical and photovoltaic characteristics of Malachite Green dye based photovoltaic cells. Journal of Semiconductors, 35, 124004-1-6.

[6]. Chakraborty K., Chakraborty S., Manik N. B., 2018. Effect of single walled carbon nanotubes on series resistance of Rose Bengal and Methyl Red dye-based organic photovoltaic device. Journal of Semiconductors, 39, 094001-1-7.

[7]. Al-Ta'ii H. M. J, Amin Y. M., Periasamy V., 2015. Calculation of the Electronic Parameters of an Al/DNA/p-Si Schottky Barrier Diode Influenced by Alpha Radiation. Sensors, 15, 4810-4822.

[8]. Tuğluoğlu N., Karadeniz S., 2012. Analysis of current–voltage and capacitance–voltage characteristics of perylene-monoimide/n-Si Schottky contacts. Current Applied Physics, 12, 1529-1535.

[9]. Yildirim M., 2017. Determination of Contact Parameters of Au/n-Ge Schottky Barrier Diode with Rubrene Interlayer. Journal of Polytechnic, 20, 165-173.

[10]. Yakuphnoglu F., Shah M., Farooq A. W., 2011. Electrical and Interfacial Properties of p-Si/P3HT Organic Junction Barrier. Acta Physica Polonica A, 120, 558-562.

[11]. Güllü Ö., Aydoğan S., Türüt A., 2012. High barrier Schottky diode with organic interlayer. Solid State Communications, 152, 381-385.

[12]. Liu C., Xu Y., Noh Y. Y., 2015. Contact engineering in organic field-effect transistors. Materials Today, 18, 79-96.

Selection and/or Peer-review under the responsibility of 2nd International Conference on Current Trends in Materials Science and Engineering, July 2019, Kolkata