Alteration of Parameters Influencing Charge Infusion of Organic Device with Multi Walled Carbon Nanotubes (MWCNTs)

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ABSTRACT

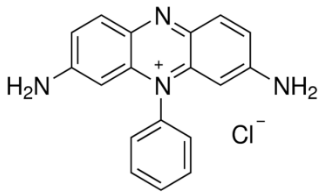
In this work, we will analyze one of MWCNTs' most important applications in the area of organic electronics. When an organic dye is sandwiched between two metallic electrodes, one of the main challenges for organic dye-based devices is the inadequate flow of active charge carriers at the metal-organic junction. High trap energy and high interfacial barrier are responsible for poor movement of active charge carriers. Improvement of charge carrier flow will increase conductivity, lower the turn-on voltage, and enable the devices to be used in various industrial uses if the traps and barrier at the metal-organic junction can be reduced. In this case, we have added MWCNTs to this organic dye-based device and investigated how they affect the interfacial characteristics. Present work will be revealing for further research into the impact of carbon nanotubes on charge infusion in organic devices.

1. INTRODUCTION

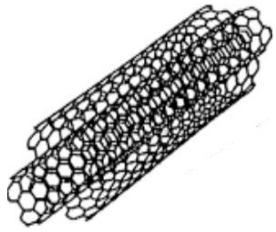
Due to their high aspect ratios, exceptional thermal and electrical properties, and large exterior area, carbon-based nanomaterials (CBNs) like single-walled carbon nanotubes (SWCNTs), multi-walled carbon nanotubes (MWCNTs), fullerenes, graphenes, and carbon-based quantum dots (CQDs) find substantial applications in numerous research fields [1-2]. Out of the varieties of CBNs, we have selected MWCNT for this study. Numerous SWCNTs are embedded inside to create MWCNTs, a unique type of carbon nanotube. MWCNTs have great electrochemical properties as well as outstanding thermal conductivity [3]. Current work studies an application of MWCNT in organic dye-based devices. Organic dye-based devices have many appealing characteristics including versatility, affordability, light weight, and large area fabrication [4]. But these important features of these devices become predominated by some insuperable hindrances at metal – organic junction when dyes are intercalated between two metallic electrodes. Device performance is greatly impacted by the metal-organic junction's poor flow of active charge carriers. Organic devices are highly susceptible to traps because of their amorphous structure [5]. As these two factors are analytically proportional to one another, higher trap concentration also results in higher junction barrier [6]. Both of these parameters can be decreased to enhance active carrier flow at the metal-organic interface, which will increase conductivity and result in a lower turn-on voltage. This is why we have included MWCNT in the organic device to investigate its impact on trap concentration and the interface barrier. Regarding formation of organic device, our organic substance of choice is the Phenosafranin (PSF) dye, which is intercalated in between Indium Tin Oxide (ITO) coated glass slide and aluminum. High trap concentration and interfacial barrier at ITO/PSF dye interface have been taken into account only. In both lack and presence of MWCNT, the prepared organic device containing PSF dye has its current-voltage (I-V) characteristics examined. The device's current flow has been examined using the Richardson-Schottky (R-S) thermionic emission method [7]. Additionally, the Norde technique has been used to verify the consistency of interfacial barrier value derived from the prepared device's I-V characteristics.

2. MATERIALS AND SAMPLE PREPARATION

Fig. 1(a) depicts PSF dye's structural composition. This colour is a cationic phenazinium group dye that can act as an energy sensitizer and is utilized in numerous biological photochemical processes [8]. PSF pigment has the empirical formula $C_{18}H_{15}ClN_4$. PSF dye and MWCNT were purchased from Sigma Aldrich in St. Louis, Missouri, and Sisco Research Laboratories in India, respectively. Fig. 1(b) depicts MWCNT's structure.



(a)



(b)

Fig. 1 Structure of **(a)** PSF dye and **(b)** MWCNT

Poly Methyl Methacrylate (PMMA) has been used as an inert binder in this study. The method for creating PMMA solution has already been described in one of our previous works [9]. The PMMA solution contains 2 mg PSF dye and is stirred for an additional 30 minutes. The next step involves splitting the solution equally into two test containers that have already been cleaned. PSF solution without MWCNT is present in one test container. To make the PSF with MWCNT solution, MWCNT is added individually to the other test tube. On an ITO-coated glass that has already been cleansed, the created PSF dye solution is spin-coated and then dried. Similar solution is also spin-coated on Al electrode. PSF dye-based device without MWCNT is formed by intercalating ITO and Al electrodes. A similar procedure is used to make the MWCNT-based PSF dye-based device. After that, these devices are dried for 24 hours in vacuum desiccators before being characterized. Fig. 2 displays a schematic of the constructed device.

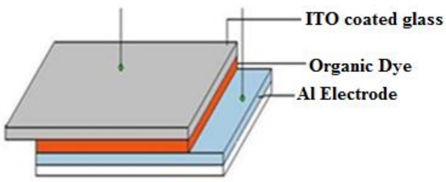


Fig. 2 Schematic of the Organic Device

3. MEASUREMENTS

Keithley's 2400 source measure unit is used to determine I-V relationship. Same methodology is used as described in an earlier published work of us [10]. Operating voltage is from 0 V to 5 V with 1000 ms delay and with increments of 0.25 V. The experimental area is maintained at 27^0C.

4. RESULTS AND DISCUSSIONS

The R-S model has been used to estimate the current flow, as mentioned in equation (1)

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

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

Equation (3) can be used to calculate the junction barrier.

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

All of the symbols have their standard meanings in this context [11–12]. Fig. 3 displays the I-V properties of the device with and without MWCNT. Fig. 3 shows that presence of MWCNT causing the current flow to almost triple.

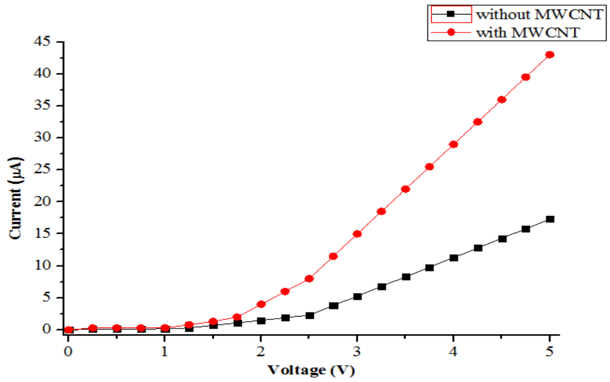


Fig. 3 I-V plot of PSF dye without and with MWCNT

Semi-logarithmic I-V features have now been plotted in Fig. 4 with and without MWCNT to determine the interfacial barrier at contact.

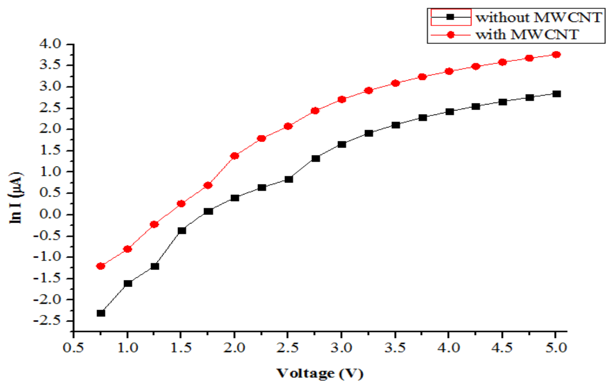


Fig. 4 ln I-V plot of PSF dye without and with MWCNT

Equation (4) can be used to describe trap energy (E_t).

$$E_t=mkT \qquad (4)$$

Where, all of the symbols have their standard meanings in this context [13] and m is derived from ln I – ln V plot of the device with and without MWCNT, which is depicted in Fig. 5.

By comparing equations (3) and (4), it can be concluded that, when other factors are taken into account, $\phi_b \propto E_t$ when E_t remains unchanged. Therefore, barrier at metal-organic contact also diminishes as the charge trapping effect does. Analytically saying, both factors are proportional to one another and are thus correlative.

The Norde formula which has been expressed in equation (5) has been used to estimate the barrier [14-15].

$$\phi_b= F\,(V_{min}) + \frac{V_0}{\gamma} - \frac{1}{\beta} \qquad (5)$$

Where, the notations have their standard meaning.

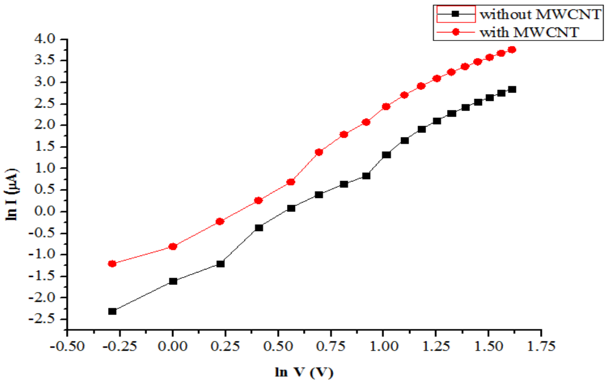


Fig. 5 ln I- ln V plot of PSF dye without and with MWCNT

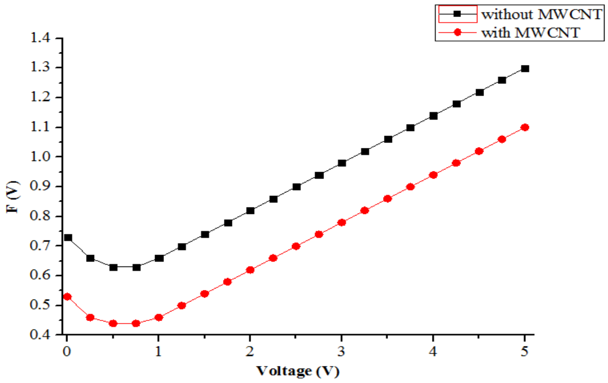


Fig. 6 Norde function plot of PSF dye without and with MWCNT

Table 1 displays the turn-on voltage, trap energy, and interface barrier values in absence and in presence of MWCNT. According to Table 1, the trap energy and interfacial barrier that influence charge infusion at the junction have been substantially reduced by MWCNT. This has improved charge infusion at the contact and improved the device's conductivity. When MWCNT is used in an organic device, the aspect ratio greatly changes the electrical properties. The improved flow of charge carriers is made possible by MWCNT's higher aspect ratio, which also lowers the percolation threshold of electrical conductivity.

Table 1: Estimation of Turn - on voltage, Trap energy, Interfacial barrier of organic devices without and with MWCNT

PSF Dye Based Device	Turn - on Voltage (V)	Value of "m"	Trap Energy (eV)	Interfacial Barrier (eV) using I-V characteristics	Interfacial Barrier (eV) Using Norde Function
without MWCNT	2.50	2.05	0.053	0.81	0.76
with MWCNT	1.50	1.85	0.048	0.75	0.69

5. CONCLUSIONS

According to the current research, certain MWCNT characteristics enable the reduction of traps and interfacial barriers that influence the current circulation at the junction area. By filling in traps, MWCNT essentially increases the number of conductive paths in the organic device. The higher aspect ratio of MWCNT plays a critical part in lowering traps and contact barriers, resulting in better conductivity, as the percolation threshold of electrical conductivity decreases with higher aspect ratio. As the turn-on voltage decreases with MWCNT, the device will turn on at lower voltages; this is also due to the organic device's increased flux of mobile charge carriers. Both the I-V and Norde methods have been used to measure the contact barrier with and without

MWCNT. Both approaches remain congruous with one another, showing a significant lowering of the contact barrier in the presence of MWCNT. This study will be helpful because it demonstrates one of the device physics applications of MWCNT in organic electronics.

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Biographies

Sudipta Sen is a UGC Senior Research Fellow (UGC-SRF) and currently pursuing Ph.D in the Department of Physics, Jadavpur University, Kolkata, India. He completed his M. Tech in Optics and Optoelectronics from University of Calcutta, in 2016 and he had secured First class first position in the M. Tech examination. He completed his B. Tech in Electronics and Communication from Calcutta Institute of Engineering and Management, Kolkata, West Bengal in 2013. He has qualified Graduate Aptitude Test in Engineering (GATE) in Electronics and Communication Engineering (EC) and in Physics (PH) and he has also qualified UGC –NET (JRF and LS) in Electronic Science. His research areas include the electrical characterization of different organic electronic devices, materials science, nanotechnology, optoelectronic devices, organic solar cells etc. He has published several research articles in numerous reputed International journals such as Springer – Nature, Elsevier, AIP publishing house etc. He has also attended several National and International conferences, seminars, workshops.

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