Methodology Report

Investigation on *I-V* for Different Heating Temperatures of Nanocomposited MEH-PPV:CNTs Organic Solar Cells

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This paper discussed the effect of different thermal evaporation treatments for nanocomposited MEH-PPV:CNTs thin films towards the performance of organic solar cells. The configuration of the organic solar cells is ITO/MEH-PPV:CNTs/Au. The heating temperature was varied from, as deposited, 50°C, 75°C, and 100°C. From the results, we observed that the efficiency increase slightly before decreasing back at 100°C. The highest efficiency was solar cells heated at 75°C with efficiency 0.001% which is supported by the *I-V* characteristics and also by the absorption spectra.

1. Introduction

Organic solar cells are gaining much interest in this energy-saving era, due to their simple and low cost fabrication process. However, the efficiency of organic solar cells is still low. Even though much research is done on blending organic material with a nonorganic material, very rare is done on blending polymer with carbon nanotubes (CNTs) because of the dispersity problem.

Even if CNTs have dispersion problems, it still has gained a lot of attention due to its unique properties. The uniqueness of the nanotube arises from its structure, which is the helicity in the arrangement of the carbon atoms in hexagonal arrays on their surface honeycomb lattices [1]. CNTs have high surface area ($\sim 1600 \text{ m}^2/\text{g}$) that offers tremendous opportunity for exciton dissociation [2]. CNTs can be metallic or semiconducting which is determined by the chirality of the nanotube. The diameter of the CNTs is an important property as it has a direct correlation with the optical band gap. The optical absorbance of CNTs is affected by both structure and dimension of the nanotube [3].

CNTs properties like high electron conductivity, high thermal conductivity, and robustness are flexible by nature and are assumed to improve the properties of a conjugated

polymer. Basically, conjugated polymer has high absorption coefficient in the visible region ($\sim 10^5 \text{ cm}^{-1}$), charge generation under illumination, and easy deposition on substrates even at room temperature [4], which makes them well-liked in recent research. Poly[2-methoxy-5-(2'-ethylhexyloxy)-p-phenylene vinylene] (MEH-PPV) is a commonly used conjugated polymer due to its solubility and absorption in the visible range [5]. The structure of electronic states of conjugated polymers is such that several types of excited states (singlet and triplet excitons) and charges (e.g., polarons) can be easily created by visible light excitation [6]. MEH-PPV is a conjugated polymer which is known as a novel class of material that combine the optical and electronic properties of semiconducting with the processing advantages and mechanical properties of plastics. It is found that the corresponding property of the matrices could be enhanced in the presence of homogeneously dispersed CNTs [7].

In order to solve the issue of undispersity of CNTs, the increase percentage of the composition is presented in this work. However, so far the agglomeration of the undisperse CNTs still exists and they are still unevenly scattered. Photoconductivity of MEH-PPV is often limited by low absorption. Therefore, in this paper we fabricate organic cells as shown in Figure 2 and discuss on the heating

TABLE 1: Description of samples.

Name of sample	Description
S_0	As deposited sample
S_{50}	Sample heated for 5 minutes at 50°C
S_{75}	Sample heated for 5 minutes at 75°C
S_{100}	Sample heated for 5 minutes at 100°C

FIGURE 1: Structure of organic solar cell.

temperature when the concentration of CNTs is high. This is due to heating temperature that also plays vital role in determining the performance of organic solar cells due to removal of moisture in the nanocomposite [8].

2. Methodology

The compositions of CNTs are fixed at 60 wt%. The CNTs used are commercially available with purification >95%. Before adding the CNTs to the polymer solution, it was annealed at 450°C for 30 minutes to ensure that all of the impurities in the CNTs are totally removed. The solvent used for dissolving the MEH-PPV powder is tetrahydrofuran (THF).

A thin layer of nanocomposited MEH-PPV blend CNTs was spin-coated with 2000 rpm for 1 minute on indium tin oxide (ITO) size 2 cm × 2 cm. The deposition was done at room temperature under normal pressure. After the deposition is done, the nanocomposited on the ITO was heated on a hot plate stirrer for 5 minutes to vaporize the solvent at 50°C, 75°C, and 100°C. The detailed descriptions of the samples are shown in Table 1. To compare the performance of the devices, as deposited, and undergo heat treatment, one device is fabricated without undergoing the treatment process. The thickness of the blended device was in the range of 50 to 90 nm. Film thickness is important in determining the efficiency of organic solar cells due to the fact that it has short diffusion length which leads to recombination. Therefore, it will yield low photocurrent and gives less energy conversion efficiency. The thickness of the nanocomposited MEH-PPV:CNTs is measured using surface profiler Veeco Dektak 750. A schematic diagram of the present solar cells is shown in Figure 1. The Au was deposited on another ITO using sputter coater so that the blended thin film was sandwiched between Au and ITO electrode.

The current density-voltage (J - V) characteristics of the solar cells were measured both in dark and under illumination at 100 mW/cm² by using an AM 1.5 solar simulator CEP 2000 Spectral Sensitivity Analyzing System. The solar cells

were illuminated through the side of ITO substrates, and the illuminated areas were 0.01 cm².

UV-visible absorption spectra were obtained by using Perkin Elmer Lambda 750 UV/Visible Spectrometer to analyze the absorbance and transmittance.

3. Results and Discussions

3.1. Electrical Properties. The measured current-voltage (I - V) characteristics of a MEH-PPV:CNTs organic solar cells in dark and under illumination are shown in Figures 2(a), 2(b), 2(c), and 2(d), respectively, where else Figure 2(e) shown the comparison for I - V characteristic under illumination for different thermal evaporation temperature. It can be seen that the I - V curve form Schottky contact when Au was used as the metal contact. The metal-semiconductor (M-S) contact in which $\Phi_M > \Phi_S$ is called a Schottky barrier diode where there is nonlinear current flow in the device. Because the current flows easily in one direction but not in the other, it is a rectifying contact. The explanation concerning this issue is that Au has work function value higher than the organic-inorganic blend. We also assumed that the Schottky formation is based on solvent used to dissolve the MEH-PPV. Naturally, MEH-PPV is a p-type material but in this paper, MEH-PPV acts as electron acceptor (n-type) and CNTs act as electron donor (p-type). The type of MEH-PPV depends on the solvent used to dissolve the polymer [9]. The Schottky formation can also be regarded as the CNTs being the metallic material and the MEH-PPV is the semiconducting part. Metallic CNTs conduct electricity easily because many electrons have easy access to adjacent conduction states.

It can be seen in Figures 2(a), 2(b), 2(c), and 2(d) that the I - V curve showed insignificant changes under illumination condition as compared to in dark due to the samples are sensitive to light. There is only a slight change for both conditions in dark and under illumination due to CNTs structure that is not compatible with the MEH-PPV polymer chain [10]. However, devices consisting MEH-PPV only show a shorter lifetime compared to organic solar cells fabricated with MEH-PPV blend CNTs [11]. Even though the current shows not much different but the MEH-PPV:CNTs nanocomposite behaves like a photoamplifier, that produce a very large current and more electrons for each photon absorbed by the polymer [12].

Figure 2(e) shows the I - V characteristics at room temperature in treated and as deposited samples. Figure 2 is the same as in Figures 2(a) to 2(d) but in Figure 2(e), we can see that S_{75} shows the highest current. It can be seen that the current tend to increase from as deposited samples to treated samples from S_{50} to S_{75} but it started to decrease at S_{100} . S_{75} showed the highest current under illumination condition compared to the as deposited solar cell. This is due to its high absorbance which is shown in Figure 5, later. The increment from as S_0 to S_{75} implies that as the temperature is increased, more charge carriers overcome the activation energy barrier and participate in the electron movement [13].

The measured current density-voltage (J - V) characteristic of a nanocomposited MEH-PPV:CNTs structure

FIGURE 2: I - V for organic solar cells with different thermal treatment: (a) S_0 , (b) S_{50} , (c) S_{75} , (d) S_{100} , and (e) comparison for I - V under illumination for (nanocomposited MEH-PPV:CNTs as deposited, 50°C, 75°C, and 100°C).

FIGURE 3: Measured current density-voltage (J - V) characteristics for nanocomposited MEH-PPV:CNTs at different heating temperature.

FIGURE 4: FESEM images of nanocomposited MEH-PPV:CNTs for (a) untreated, (b) treated.

FIGURE 5: Absorbance spectra for nanocomposited MEH-PPV:CNTs for different heating temperature.

TABLE 2: Measured parameters of the solar cells.

	As deposited	50°C	75°C	100°C
V_{oc} (V)	0.097	0.094	0.091	0.079
J_{sc} (mA/cm ²)	0.033	0.031	0.052	0.029
FF	0.243	0.269	0.229	0.255
η (%)	0.0007	0.0008	0.001	0.0006

under illumination are shown in Figure 3. Photocurrent of 0.052 mA/cm² is observed under illumination for S_{75} which is the highest as compared to the other solar cell. This support the assumption where absorption of light in the MEH-PPV:CNTs, followed by the separation of carriers at the interface. Where else the lowest photocurrent is shown for S_{100} with 0.029 mA/cm². This occurred due to the degradation of the MEH-PPV emission properties [14]. Measured parameters of these solar cells are summarized in Table 2. S_{75} showed the highest efficiency which is 0.001% but it has the lowest fill factor (FF) compared to the other solar cell and it has lower open circuit voltage (V_{oc}) compared to the S_0 solar cell.

3.2. Surface Morphology. As can be seen in Figures 4(a) and 4(b) above, no difference can be seen in the morphology of the samples. The dispersion of CNTs in the MEH-PPV still occurs and was unevenly scattered. This is because of the bonding of the CNTs that is not easy to break in order to robust in the polymer matrix. Therefore, we supposed that by adding more CNTs to get well scattered CNTs are not doing well. Another reason of the undispersity was because of the solvent effect [14]. Formation of large CNTs agglomerates is observed because of using nonaromatic solvents instead of aromatic solvents [9].

3.3. Optical Properties. The absorption spectra of MEH-PPV blend CNTs are presented in Figure 5 for various heating temperature of MEH-PPV:CNTs with samples as deposited, S_{50} , S_{75} , and S_{100} , respectively. The maximum absorption occurred at wavelength around 500 nm. The peak did not show any shift either to red or blue light. There is no noticeable wavelength shift observed in the absorption maximum in MEH-PPV:CNTs nanocomposite films, but there is a substantial drop in the magnitudes due to reflectance of light when it heat the undisperse CNTs. As the heating treatment increase, the peak of absorption spectra decrease with respect to the sample as deposited, while sample S_{75} showed the highest absorbance with the value more than 1. We assume that at 75°C the solvent was completely vaporized. This is directly related to the I - V characteristic where the same sample showed the highest current. S_{75} absorbed the most light when it is illuminated. Therefore, the excess carriers were excited the most at this sample, where else at 100°C, the polymer was not capable to perform due to reaching its maximum temperature at 75°C where at this temperature, it can be demonstrated that the solvents are completely vaporized. However, the changes cannot be seen from the surface morphology analysis.

4. Conclusion

It can be concluded that MEH-PPV:CNTs nanocomposite shows a Schottky contact when Au is used as the metal contact. There is a slight change for I - V in dark and under illumination condition which shows that CNTs influence the behaviour of the conjugated polymer. The highest I - V is shown for sample undergoes heat treatment at 75°C. This is supported by the highest absorbance also occurred at 75°C. At 100°C, the nanocomposited MEH-PPV:CNTs was not capable to perform due to its decrement in its photoamplifier properties. From the surface morphology images, the dispersion of CNTs in the polymer matrix also does not show remarkable results that will influence the overall results.

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