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Optimizing Multiwall Carbon Nanotube Weight Ratio for Efficient Charge Transport in Hybrid TiO_2 / Polymer Solar Cells

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***Abstract*— This study focuses on enhancing the charge transport in hybrid TiO_2/ P3HT solar cells by incorporating Multi Wall Carbon Nanotube (MWCNT) within the nanoporous TiO_2 electron transporting layer. We systematically changed the weight ratio of MWCNTs which was blended with TiO_2 nanoparticles and studied the effect caused in hole-mobility using Time of Flight technique. We found two orders of magnitude increase in hole-mobility while adding 0.02wt % MWCNT into porous TiO_2. This is consistent with the corresponding current-voltage characteristics of above solar cells.**

I. INTRODUCTION

Hybrid nanoporous titanium dioxide (TiO_2)/Poly(3-hexylthiophene) (P3HT) polymer solar cells is one of the promising technologies in the development of low cost organic photovoltaic devices. Commercialization is mainly limited by its low efficiency compared to so-called organic bulk heterojunction (BHJ) devices. It was reported that this low efficiency arises mainly due to the inefficient charge transport in the disordered donor/acceptor materials and a number of works have been carried out to improve its power conversion efficiency[1-6]. Although a few independent studies had been reported to find the electron mobility in porous TiO_2[7]and hole mobility in poly(3-hexylthiophene) (P3HT)[8], no successful study on charge transport in TiO_2/polymer composite materials has been reported by employing Time of Flight (TOF) technique. Several techniques have been used in addition to modifying the metal oxide surface using thin molecular layer to improve the hole-mobility in hybrid structures including controlling polymer alignment to enhance the overall device performance[9]. It has also been reported that the thin layer of alumina reduces the recombination kinetics of the TiO_2-P3HT solar cells and thus improves the overall performance of the device[3]. Recently we reported that the hole-mobility in Ruthenium based dyes (Z907, N719) treated TiO_2/P3HT nanocomposite is an order of magnitude higher than the corresponding untreated nanocomposites[10]. In this work we systematically incorporated multiwall carbon nanotube (MWCNT) into the TiO_2 electron transporting layer and studied the effect caused in hole-mobility using time of flight technique.

II. EXPERIMENTAL PROCEDURE

A. Fabrication of Solar cell

Samples were prepared on patterned Indium Tin Oxide (ITO) coated glass substrates (12mm x 12mm, 10Ω/square), which were cleaned similar to those reported elsewhere[11]. A dense hole blocking layer was deposited by spray pyrolysis. For the deposition of TiO_2:MWCNT blends, an ethanolic suspension of MWCNTs of 0.1 mg/ml was prepared and sonicated to obtain a good dispersion of MWCNTs. A precise amount was then mixed with a known weight of TiO_2/ethanol solution to obtain mixed composite containing fixed percentages, 0.01, 0.015, 0.02, 0.03 and 0.04. This solution was spun coated over the dense layer followed by sintering. Thin layer of Z907 was deposited by dip coating and then the samples were dipped in P3HT overnight prior to P3HT spin coating. Subsequently molybdenum trioxide (MoO_3) layer was deposited by thermal evaporation through a shadow mask under high vacuum as an electron blocking layer. Eventually the top contact Ag was deposited and annealed to improve the contacts during measurements.

B. Characterization technique

The carriers were generated with a frequency-doubled Nd:YAG laser (spectral wavelength 532 nm, pulse width less than 6 ns, energy per pulse ~ 10 μJ, repetition rate 1 Hz, and nominal beam diameter 2-8 mm), illuminating through the ITO. The photocurrent transients were monitored with a TDS 1012B (Two channel Digital Storage oscilloscope) while ITO terminal with positive potential. The optical absorption measurements were performed using UV-Vis spectrometer (JENWAY-6800).

III. RESULTS AND DISCUSSION

The improved performance of the device could be interpreted in terms of the modified optical and transport properties resulted from the addition of MWCNT. The TiO_2 photoelectrode absorbs only photons of energy $\geq$ 3 eV, consequently, the remaining portion of the solar radiation is transmitted to the photon absorbing layer beneath the TiO_2 layer. Figure 1 (a) compares the absorption features of MWCNT incorporated TiO_2 nanoporous layers with that of the bare TiO_2 nanoporous layer and Figure 1 (b), shows the absorption spectra of P3HT dip coated TiO_2:MWCNT/Z907 and TiO_2/Z907 structures.

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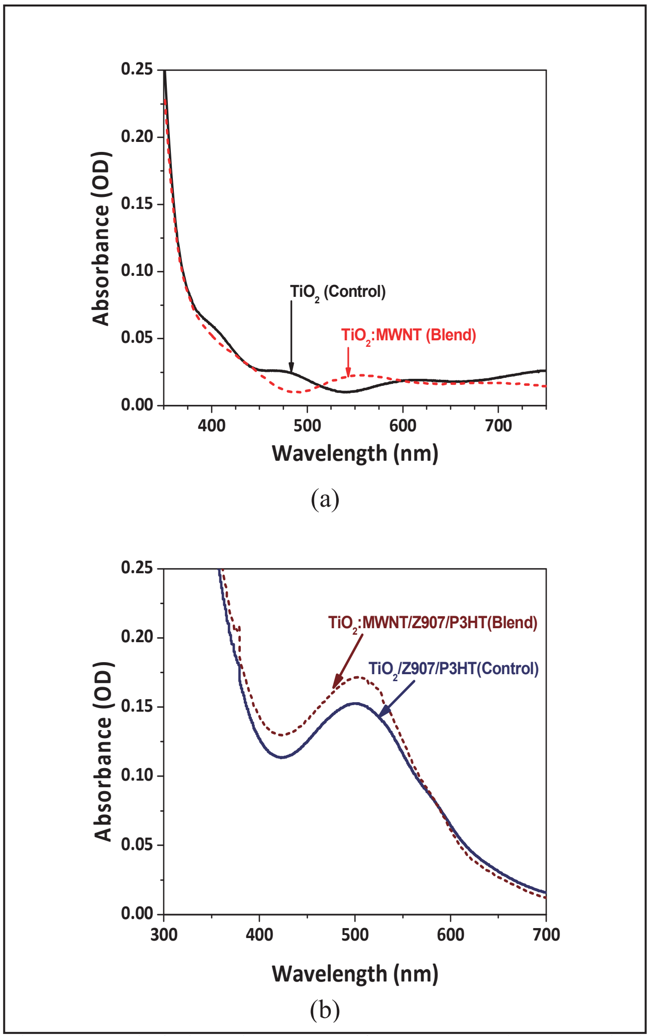

(a)

(b)

Figure 1. Optical absorption spectra of (a) MWCNT incorporated TiO_2 nanoporous layer and bare TiO_2 nanoporous layer and (b) P3HT dip coated TiO_2:MWCNT(0.02wt%)/Z907 and TiO_2/Z907 structures.

The spectra (Figure 1 (a)) clearly depict that there is almost no contribution from MWCNT for the absorption. The peak absorption wavelength does not change by the incorporation of MWCNT in the active layer but it influences the maximum absorption intensity with respect to different weight percentages. Further we observed quenching of the absorption for the films with higher weight percentage of MWCNT within the porous TiO_2 layer, which can be attributed to the interaction between the P3HT and MWCNT. We found that the hole-mobility in Ruthenium based dye (Z907) treated TiO_2/P3HT nanocomposite is an order of magnitude higher than the corresponding untreated nanocomposites. In this work we observed that the hole-mobility of TiO_2-MWCNT/Z907/P3HT nanocomposite is further improved, over two orders of magnitude higher than that of TiO_2/P3HT nanocomposites and this higher mobility was achieved when the weight percentage of MWCNTs is 0.02 % in MWCNT-TiO_2 blends and this is probably due to the well aligned path ways formed in the nanocomposites for efficient charge transport. The variation of hole-mobility with respect to the weight ratio of MWCNT in the blends of MWCNT-TiO_2 is shown in the following figure.

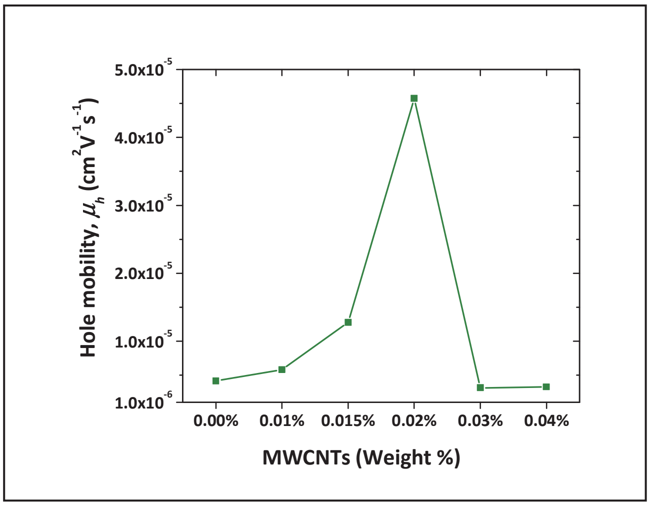

Figure 2. Hole-mobility variation with the weight percentage of MWCNT in ITO/denseTiO_2/MWCNT-TiO_2/Z907^d/P3HT^{d,s}/MoO_3/Ag device, where superscripts d and s indicate dip and spin-coated layers, respectively.

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