

High open-circuit voltage bulk-heterojunction solar cells by using new dendritic acceptor material

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ABSTRACT

Many conjugated dendrimers combined with polymers are used in the formation of active layers (donor- acceptor) in organic photovoltaic due to their electronic properties and the ability to tune their absorption ranges. They have low viscosity, good solubility and multifunctionality. We have applied a new dendrimer acceptor material Poly(amido amine) (PAMAM) dendritic wedge G0.5 (UV absorbance at 445 nm, and Fluorescence emission at 512 nm in MeOH) in organic bulk-heterojunction (OBHJ) solar cell in order to improve their performance and morphology. The low band-gap polymer Poly (3-hexylthiophene-2,5-diyl) (P3HT) was used as the donor material. We obtained high V_{oc} (1 V) and I_{sc} (2×10^{-3} mA/cm²). The result shows that Poly(amido amine) (PAMAM) dendritic wedge (C28H28N4O5) is a promising acceptor for high performance OBHJ solar cells. Also, the morphology of the active layer was improved.

Keywords: PAMAM dendritic wedge, P3HT, OBHJ solar cells.

1 INTRODUCTION

Dendritic materials can be divided into hyperbranched polymers, dendrons and dendrimers are new materials which can be used in organic solar cell applications [1]. Dendrimers are new class of polymeric materials composed of highly branched, well-defined and monodisperse macromolecules, which can enhance charge transport and film morphology [1, 2]. They have unique property over conventional polymers such as low viscosity, good solubility, nano-scaled size, low-disparity and multifunctionality which make them important materials in many application areas including organic solar cells [3]. In the last few years, conjugated dendrimers combined with polymers are reported as the main materials for the formation of active layers in organic photovoltaic. Organic bulk-heterojunction structure (OBHJ) consists of blended donor and acceptor layer deposited between two electrodes in order to gain a large interface area between donor and

acceptor [4]. However, charge mobility through the OBHJ active layer strongly depend on the morphology of active layer. thus, dendrimers materials with their small size and monodisperse nature leads to a high degree of ordering in organic solar cell devices and thus high carrier mobilities [5, 6].

It is very well documented that dendrimers structures contain core, branches (dendrons), and end groups (surface groups). The core responsibility is to controls the absorption of light where the charge transport and molecules separation take place within the dendrons. The end groups determine the solubility of the dendrimers. The most important parameter of these structures is the ability to tune each component separately. One of the main advantages in using dendrimers materials in the application of organic solar cells is the ability to blend without any phase separation. This blend would be covering the whole solar spectrum which leads to harvest much more light and enhance the photovoltaic device performance [7].

Because of their strong fluorescence and good photostability [8] derivatives of 1,8-naphthalimide are used as fluorescent pigments and dyes [9], light emitting diodes [10-12], photo-induced electron transfer sensors [13-15], fluorescent switches [16-18]. The attractive properties of the 1,8-naphthalimide chromophore have led to its incorporation into numerous polymeric [19, 20] and dendritic [21-25] structures so as to tailor solubility, self-association and molecular size to suit a particular application. A number of 1,8-naphthalimide derivatives were screened for fluorescence and 7*H*-benz[*de*]benzimidazo[2,1-*a*]isoquinoline-7-one (BBIQ) selected for use as the fluorophore due to its strong fluorescence [14, 26].

As well as being the first high-generation dendrimers and one of the most studied [27], poly(amidoamine) (PAMAM) dendrimers are also very hydrophilic, has more aliphatic PAMAM bone which is used as a flexible light harvesting antennae with high efficiency electron transfer [24, 28]. Also PAMAM can be synthetically modified to possess

fluorescent 1,8-naphthalimide derivatives at their core and/or peripheries as an acceptor for light harvesting application [29].

In the last few years Poly (3-hexylthiophene) (P3HT) became one of the main organic semiconductors used in the fabrication of thin film transistors [30], organic memories [31]. In the field of organic solar cells, and due to the low bandgap and wavelength absorption of 300-650 nm, P3HT is widely used as a donor, in particular in the formation of active layer in OBHJ solar cells [6].

Here we report on the application of a new PAMAM dendritic molecule as an acceptor material while the low band-gap (P3HT) was used as the donor material in OBHJ solar cells in order to improve their performance and morphology.

2 EXPERIMENTAL SECTION

The structure of the OBHJ solar cells is ITO/40 nm PEDOT/130 nm P3HT: G0.5 /20 nm TiO_x/Al as shown in Fig. 1. First, ITO-coated glass substrate was cleaned, then a layer of 40 nm thickness (hole extraction layer) of poly(3,4-ethylenedioxyethiophene)-polystyrene sulfonic acid (PEDOT:PSS, Baytron P) was spin coated (at 5000 rpm for 40 second) and annealed at 140°C for 10 minutes. A combined mixture of P3HT (1 wt%) and PAMAM G 0.5 (2 wt%) in chloroform solution was spin coated inside a glove box under nitrogen environment at 2000 rpm for 60 second, with a thickness of about 130 nm. Afterward, a TiO_x solution (electron transport layer) was spin coated (5000 rpm at 20 second) with a thickness of about 20 nm. Finally, a 100 nm Al was evaporated on the active layer.

The device active area defining by cathode (Al) was 0.12 cm² on the top of active layer. Atomic force microscopy (AFM) was used to characterize the surface roughness and morphology of the active layer. The current-voltage (*I-V*) characteristics of the OBHJ devices were measured using HP-4140B pA meter/dc voltage source in combination with a Solar Cell Characterization Vacuum System (in house made system).

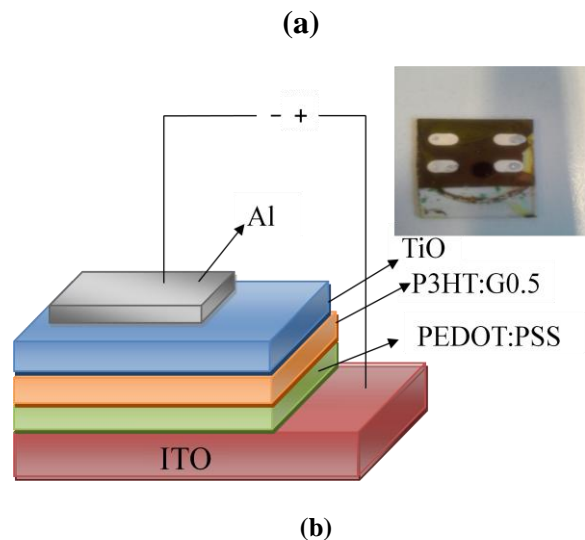
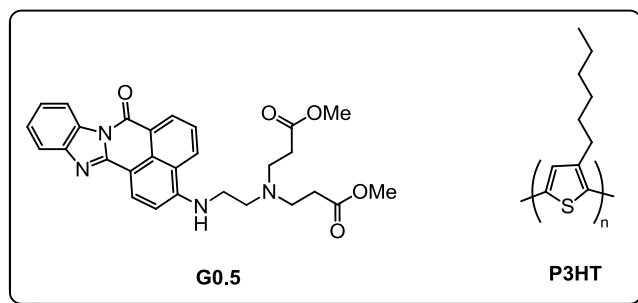


Figure 1 (a) Active layer materials chemical structures. (b) A schematic diagram of the OBHJ solar cell structure, inset is the optical image of the OBHJ device.

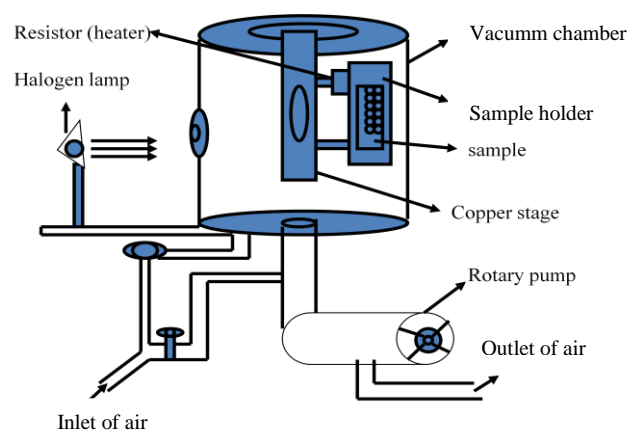


Figure (2) Schematic diagram of the designed vacuum system.

3 RESULT AND DISCUSSION

All devices were characterized in air and at room temperature. Figure 3 shows the AFM images of the surface topography of P3HT: PAMAM G0.5 thin film deposited on PEDOT: PSS film. It is clear from the AFM images (of 5 μm dimension) that the surface of the active layer more of amorphous film as the films shows very low roughness. Figure 4 shows typical current density vs voltage (J - V) characteristics under for a solar cell under $100 \text{ mW}/\text{cm}^2$ AM1.5G white light. The open circuit voltage (V_{oc}) and the short circuit current (J_{sc}) associated with this structure were 1 V and $2 \times 10^{-3} \text{ mA}/\text{cm}^2$ respectively. The fill factor (FF) was estimated to be 30% and the power conversion efficiency (η %) of about 0.001 %. Although the device efficiency is rather low for this new acceptor material, however it shows much improved open circuit voltage and reasonable short circuit current. Such a behavior was expected for these devices as it was reported by Optiz et al and Yang et al [32, 33] when the active layer shows amorphous like film the device would produce high V_{oc} and low J_{sc} . It was also stated that amorphous thin film for the materials with long branched side chains and weakened intermolecular interactions, leading to an increased V_{oc} but a lower J_{sc} [33].

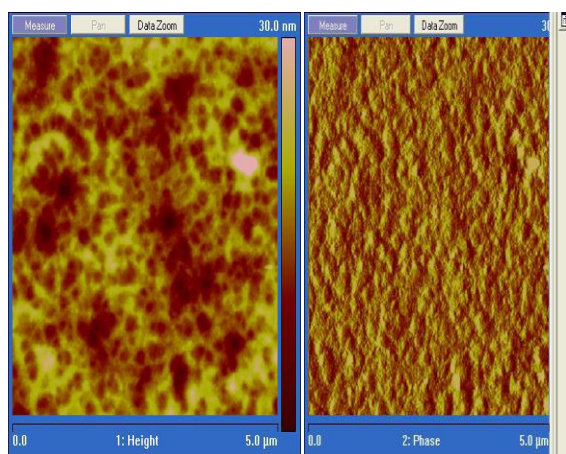


Figure (3): AFM images for the active layer blend P3HT:PAMAM G0.5

The optical absorption spectroscopy shows in Fig. 5 reflects the formation of active layer microstructures (P3HT: PAMAM G0.5). It is very well known that P3HT absorption edge is about 690 nm and from Fig. 5 the complementary absorbance of P3HT and PAMAM G0.5 shift to 850 nm where the peak is 650 nm. This confirms what have been reported in the last few years that dendrimers can absorb light at much longer wavelengths [32].

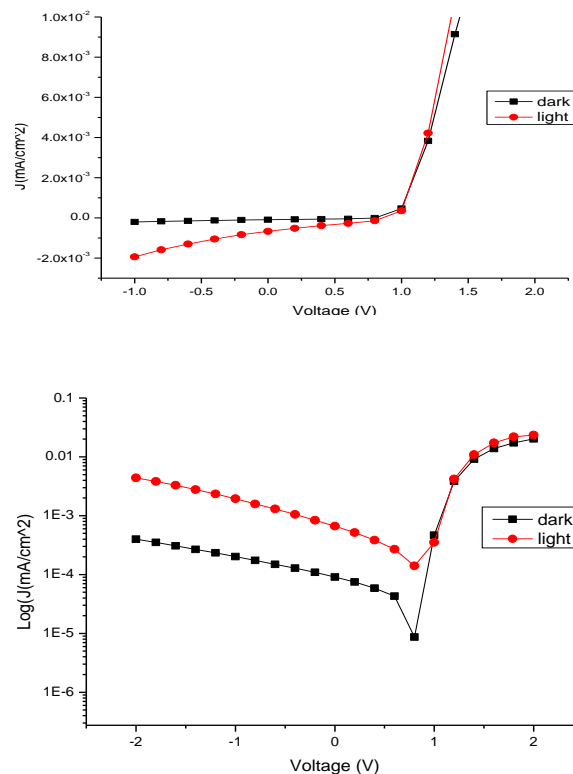


Figure 4 Current density – voltage characteristics measured under dark and illumination of the blend P3HT: PAMAM G0.5.

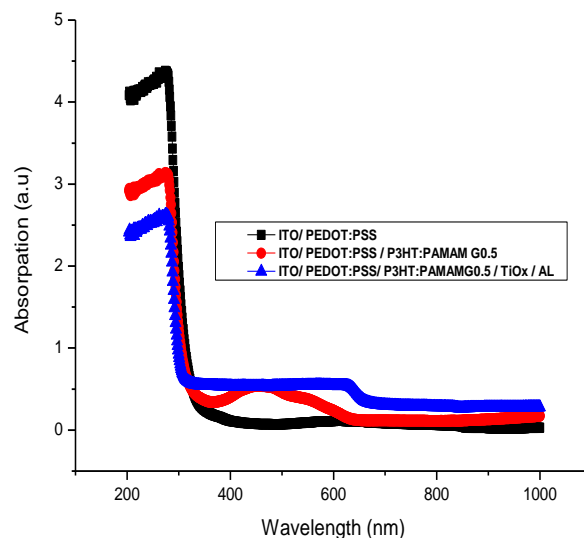


Figure 5 The absorption of the OBHJ solar cell

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