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High stability of benzotriazole and benzodithiophene containing medium band-gap polymer solar cell

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ABSTRACT

The improvement of polymer solar cell stability is a challenge for the scientists and has significant implications commercially. In this study, we investigated the stability of a novel P-SBTBDT active material applied in an inverted type solar cell. Detailed stability experiments comprising shelf life, laboratory weathering and outdoor testing were carried out according to ISOS testing guidelines. Shelf life showed that P-SBTBDT solar cells were very stable after 840 h with encapsulation. Although accelerated weathering aging tests are a very harsh, the devices remained stable after the burn-in phase with T_{50} from 700 to 840 h, with some P-SBTBDT solar cells did not reach T_{50} in the time span of the test. Degradation tests on the P-SBTBDT solar cells which were carried out under natural solar light indicated that T_{40} was reached after 840 h. The results of dark, light, damp and dry stability tests showed that most of the degradation was provoked by failure of the encapsulation. The experiments indicated that P-SBTBDT solar cells are sensitive to light and oxygen but are strikingly stable under humid conditions. Further developments for minimizing the degradation effects using UV-filters and better encapsulation are some of the necessary improvements in further research.

1. Introduction

Polymer solar cells (PSCs) are attracting significant attention at present since they are renewable materials to produce electricity with light weight, and relatively low cost of production [1–4].

Inverted type polymer solar cells show better long-term stability compared to normal device geometry polymer solar cells since there is no need for the acidic hole-transporting layer; poly(3,4-ethylenedioxylenethiophene):poly(styrenesulfonic acid) (PEDOT:PSS) and low-work-function metal cathodes which reduce device lifetime [5–8]. Vertical phase separation in the active layer is a superior advantage for inverted solar cells, since it leads to more efficient exciton dissociation [9]. This can be considered as a self-encapsulated device since durable metals are used as the top electrode [10]. It is quite challenging to fabricate PSCs that yield high power conversion efficiency (PCE) while retaining good ambient stability [11].

Degradation of OPVs is a complicated issue and is not yet fully understood. There are a variety of factors that affect the stability of OPVs. Chemical reactions between O_2 and H_2O molecules and the active layer and electrode materials. Diffusion of electrode materials and their reactions with the active layer, delamination of the cathode, nano-phase modifications and photo-oxidation of the active layer [12] also contribute to the overall degradation of OPVs. Furthermore, many of these degradation mechanisms are interrelated; creating additional complications in understanding the overall degradation process [13–15].

Oxygen (O_2) and humidity can diffuse through grain boundaries and pinholes into the device and deteriorate polymer/organic materials. Since metal electrodes are in direct contact with the active layer, the metal can penetrate and react with the active layer. To eliminate this effect, metal oxides are used as buffer layers between the polymer and metal electrode where their use improves the device durability [16–19]. The main drawback of conventional polymer solar cells is rapid

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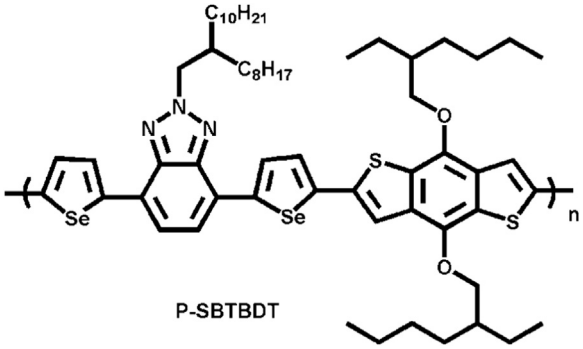

Scheme 1. Synthetic pathway and chemical structure of **P-SBTBDT**.

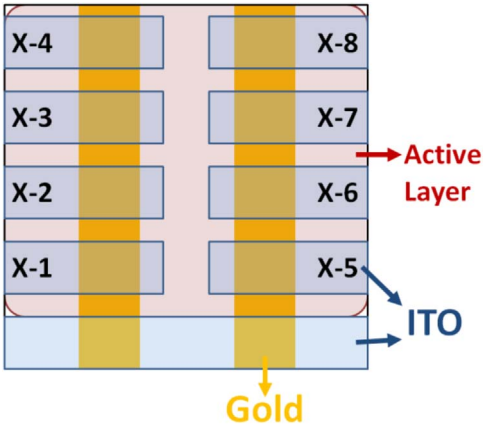

Fig. 1. Module design and cells identification. X represents the name of the sample.

oxidation/water reaction of the aluminum (Al) electrode [20]. Inverted solar cells are a good approach to solve this problem since the architecture uses the ability to reverse the polarity of charge collection [21–28]. Instead of an aluminum electrode, metals such as silver (Ag) or gold (Au) are used for the electrodes in inverted structure solar cells. Titanium oxide (TiO_2), Zinc oxide (ZnO) among others can be used as the buffer layers between polymer and metal electrode.

Medium band gap polymers can also be used for the fabrication of PSCs. These can be designed with a suitable donor (D) and acceptor (A) segments in the polymer chain and with high LUMO level acceptors [29–31]. In this letter, selenophone units were inserted between benzotriazole (BTz) and dialkoxyl-substituted benzo [1,2-b:4,5- b′]dithiophene (BDT) molecules which provided high mobility and improved photon harvesting (Fig. 2a). Selenophene substitution facilitated the development of conductivity and mobility due to Se-Se intermolecular interactions. Selenophene containing polymers indicated a good planarity and an extended conjugation length. Selenophene containing polymers compared to other chalcogeophene derivatives exhibit lower band gap, since LUMO level is deeply reduced, whereas HOMO is not changed [32–34]. Moreover,

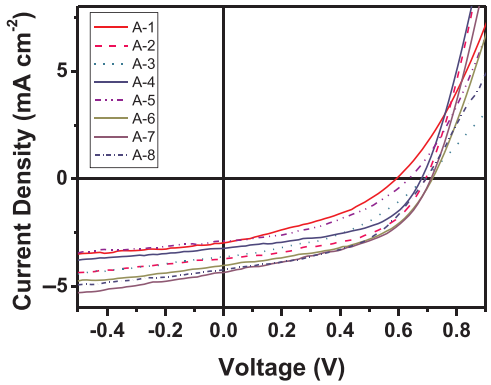

Fig. 3. IV-characteristics of inverted **P-SBTBDT** solar cells without post annealing (devices are A-1 to A-8).

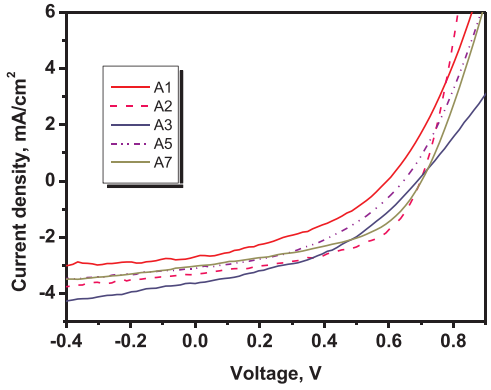

Fig. 4. IV-characteristics of inverted **P-SBTBDT** solar cells after post annealing (devices are P A-1 to P A-7).

selenophene, BDT, BTz containing polymers have high hole mobilities.

In this paper, we investigated the stability of novel P-SBTBDT solar cells. The stability measurements were carried out according to the ISOS protocols [35]. ISOS protocols are a set of guidelines that explain the procedures of organic solar cell stability measurements under different test conditions. Laboratory indoor (ISOS-L-1, ISOS-L-2, ISOS-L-3, ISOS-D-1, ISOS-D-3) and outdoor tests (ISOS O-1) of PSCs were performed in order to unveil and address the weak points in the device durability. With further development, it is expected that P-SBTBDT solar cell will approach the goal of 10000 h lifetime under outdoor conditions.

2. Experimental

2.1. Materials

Polymer (Scheme 1) were synthesized with the route reported previously [36]. n-Type semiconductor phenyl-C_{71}-butyric acid methyl

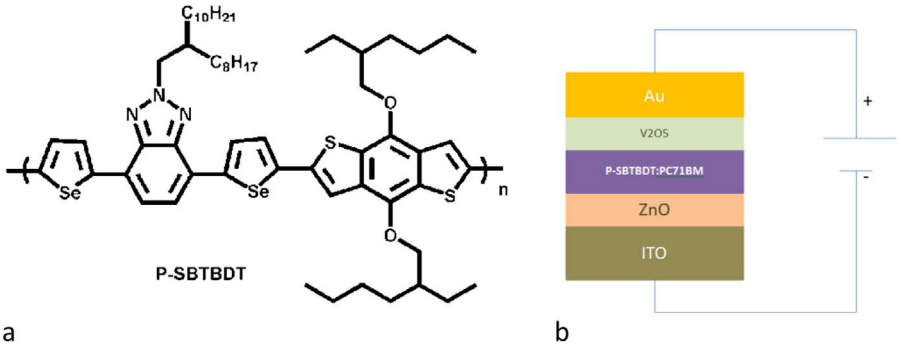

Fig. 2. a) Chemical structure of **P-SBTBDT**, b) Inverted solar cell architecture **P-SBTBDT** solar cells.