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Efficiency enhancement of organic photovoltaic modules prepared via wash processing

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ABSTRACT

To enhance OPV performance, a novel module-fabrication process was developed. Chlorobenzene and acetone were employed to wash away unnecessary residual high-resistance materials after full modules were fabricated. Monolithic interconnecting electrode lines between the anode and the cathode were formed using a dispenser after wash process. The wash process allowed for minimization of interconnection resistance and enhancement of power conversion efficiency. Module efficiency changes were also studied by varying the coating conditions of PEIE. The power conversion efficiency increased as a result of the wash-off process compared with modules fabricated via conventional processes. The power conversion efficiency enhancement was attributed to increases in open circuit voltage and fill factor. Applying this wash-off process to larger-area OPV modules is expected to be effective for further enhancing power conversion efficiency.

1. Introduction

Due to the demand for sources of inexpensive renewable energy, organic photovoltaics (OPVs) have attracted a large amount of research and development focus in the last two decades [1–7]. Before OPVs can replace conventional power generation methods, it is important for the technology to be price competitive. This can be achieved through the utilization of mass production fabrication techniques such as roll-to-roll processing. Roll-to-roll processing technology, with its high production throughput, is recognized as a method for low-cost mass production of large-area flexible organic electronics [8–18].

Since the first roll-to-roll-processed OPV module was reported by Krebs, many developmental studies have been conducted [15]. For use in everyday power applications, an OPV module structure must have connections between sub cells. Series connections are the most commonly employed method due to their relative ease of processing. Furthermore, according to OPV module shading tests, 10% shade exposure can shut down an entire module [19]. Therefore, optimized module fabrication technologies are critical to yield the maximum power output for a given module area. For example, we previously demonstrated that longitudinal partitioning of the OPV module leads to enhancement in efficiency [20]. Many studies have assessed the effects of module geometry on power conversion performance.

In this study, we investigated the influence of OPV module fabrication methods on module performance. In particular, we studied the ability to form ohmic contacts as a result of washing away unnecessary active and transporting layers and correlated this ability with enhanced module performance.

2. Materials and methods

2.1. Module fabrication

In this study, 100 mm × 100 mm^2 ITO glass substrates were etched via photolithographic processes to yield seven sub cells with 8-mm-wide ITO stripes. Prepared substrates were cleaned in series with acetone, isopropyl alcohol, and de-ionized water in an ultrasonic bath for 10 min. Subsequently, the substrates were dried under nitrogen gas in a 120 °C convection oven. Atmospheric pressure plasma (Power: 8 kV, N_2 gas: 200 l/m) was used to increase the wettability of the substrates. An electron extraction buffer layer was formed using 0.4 wt% polyethylenimine, ethoxylated (PEIE, purchased from Sigma-Aldrich, MW=75,000) stock solution (dissolved in 2-methoxyethanol) in conjunction with a slot die coater (coating speed was 10–20 mm/s, shim plate thickness was 30 µm), followed by drying at 110 °C for 10 min in a convection oven. The resulting PEIE layer thickness was 5–10 nm

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as measured with a thickness profiler (TENCOR®, P-10 α-step). Next, 4.6 wt% P3HT (purchased from Rieke Metals, EE grade) and PCBM (purchased from Nano-C) were blended and dissolved in anhydrous chlorobenzene at a 1:0.6 weight ratio. The dissolved polymer blend solution was slot die-coated onto ITO glass/PEIE at a speed of 15 mm/s. The resultant active layer was 230 nm thick and was dried at 110 °C for 12 min. The hole extraction layer was generated by screen printing a PEDOT:PSS (Agfa EL-P5010) coating layer and was dried at 110 °C for 10 min. A silver paste (Toyo UV) coating was also applied via screen printing (width of silver electrode was 6 mm) and was sintered using heat and UV light (110 °C for 10 min and 1 min at 2400 mJ). Following fabrication of the OPV module, unnecessary buffer and active layers were removed by sequential washing with chlorobenzene and acetone solutions. Monolithic interconnecting electrode lines (formed with Elcoat p-100 whose width was 2 mm) were subsequently formed using a dispenser.

2.2. Characterization

A Class AAA Xe solar simulator (McScience K3600) was used as a light source, and all measurements were performed under a 1 sun condition (100 mW/cm^2). Measurements were not corrected for reflection losses or absorptions from the ITO electrode. The *I–V* performance was measured with a Keithley 2400 source measurement unit. The cross-sectional analysis was performed by TESCAN Lyra3 dual beam FIB analyzer (Resolution in high vacuum is 1.2 nm at 30 kV).

3. Results and discussion

Conventional OPV modules are formed through series connections of several sub cells to yield the maximum power output for a given module area. We investigated the influence of ohmic contacts, formed by washing away unnecessary active and transporting layers, on the performance of the OPV module. In this study, inverted OPV modules were prepared. To simulate a roll-to-roll processing environment, all fabricated device layers were formed via slot die-coating or screen printing. Fig. 1 reveals the

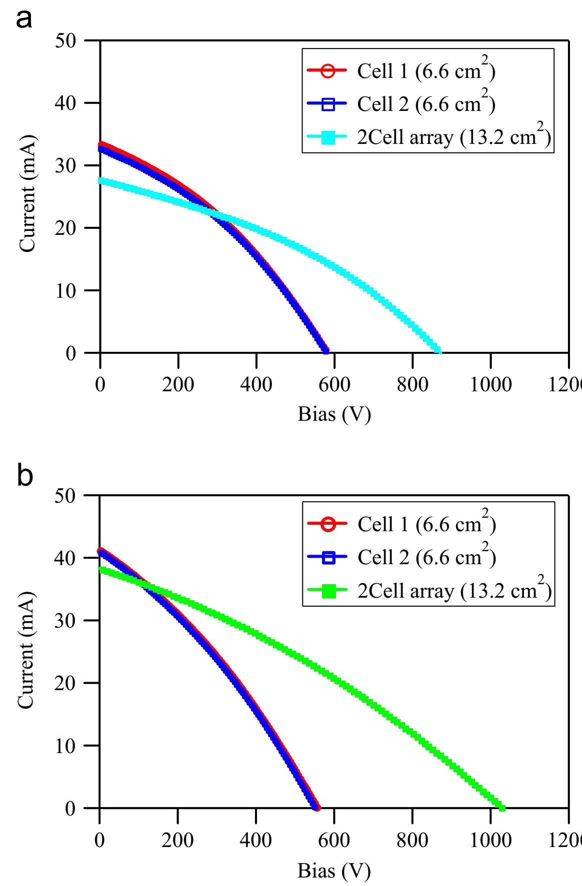

Fig. 2. *I–V* characteristics of sub cells and two cell array; (a) conventional process, (b) wash-off process.

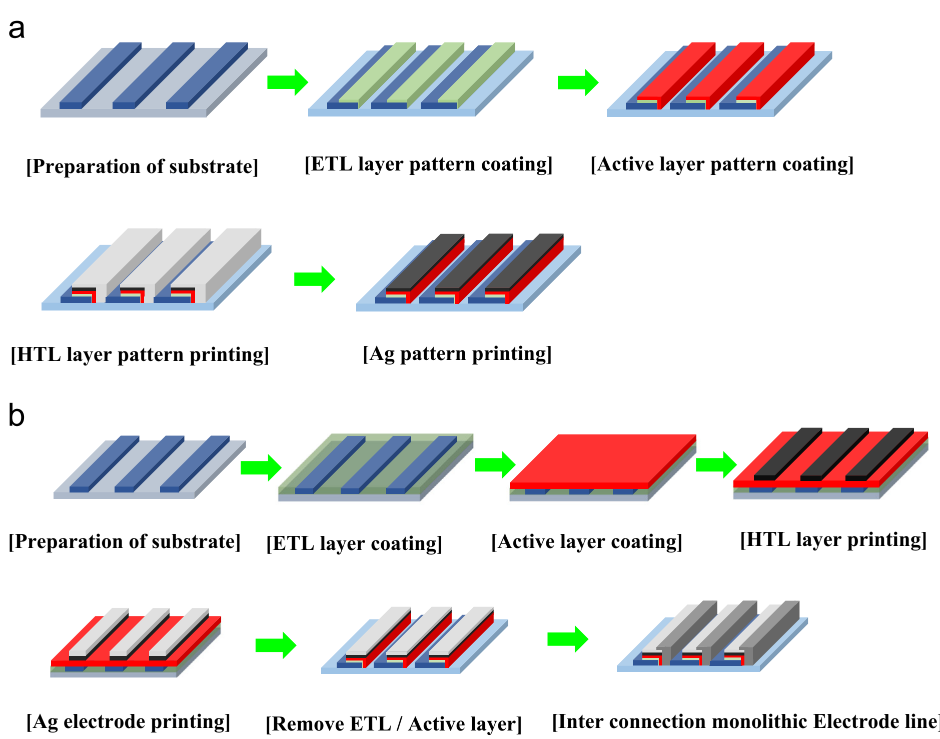

Fig. 1. OPV module fabrication process; (a) existing standard fabrication process, (b) low TCO-metal interfacial contact resistance process (wash-off process).