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Solution-Processed Inverted Organic Photovoltaics on Metal Foil Substrates

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1. Introduction

Organic bulk heterojunction photovoltaic cells fabricated from both polymers [1] and small molecules [2] are an area of intense research because they show promise as a lower-cost alternative to their inorganic counterparts. Much of this cost reduction relies on the ability to use high-throughput processing techniques with these materials such as roll-to-roll coating using materials from solution. In addition, organic molecules do not require high temperature processing, also reducing the energy cost of fabrication.

To date, all polymer photovoltaic cells have a solution-processed active layer, and some include solution-processed buffer layers [3] or electrode modifying layers [4] but no inverted organic photovoltaic cell has been reported in which every layer in the cell including the top electrode is deposited from solution onto a metal foil substrate. This is desirable because metal foils are not only cheap, they provide better barrier properties than glass or plastic substrates, and if every subsequent layer is deposited from solution this eliminates the costly and energy-intensive need for vacuum processing.

2. Device Fabrication and Characterization

100 nm of silver was evaporated onto pre-cleaned glass substrates to serve as the metal foil substrate electrode. In practice, this substrate would be prepared by plating a thin layer of silver on a low-cost metal foil such as aluminum foil. The bulk heterojunction active layer consisted of a 1:0.8 wt% ratio of poly(3-hexylthiophene) (P3HT) and phenyl-C60-butyric acid methyl ester (PCBM) in chlorobenzene. This solution was spin-cast on top of the silver, followed by the poly(3,4-ethylenedioxythiophene)-poly(styrenesulfonate) (PEDOT:PSS). The PEDOT:PSS used in this study was the H. C. Starck formulation Baytron P CPP 105D as it contains additives that have been shown to improve its wetting properties on top of hydrophobic organic layers [5]. Following the method of Ravirajan et al. [6], the PEDOT:PSS was sonicated for 15 minutes followed by heating at 90°C prior to spinning in order to obtain a smooth film.

Silver nanowire electrodes were prepared on a separate pre-cleaned glass substrate by drop casting the wires from suspension and allowing them to dry while agitated on a shaker [7]. They were then annealed separately at 180°C for one hour and laminated onto the rest of the device. The lower Ag electrode was exposed for device measurement by dissolving the nanowires and active layer with acetone.

All device measurements were taken in air using a 1.5AM spectrum at approximately 1000W/m^2 and using an HP4145B semiconductor analyzer.

3. Results

Figure 1 shows the device structure. The cell area is 5 mm^2. The laminated nanowire electrode is visible on the right side at its edge and covers the active cell area. In this case the silver was patterned, but in future devices a large area metal foil could serve to connect the individual cells and either the active layer or the nanowire electrode could be patterned through printing to separate the devices.

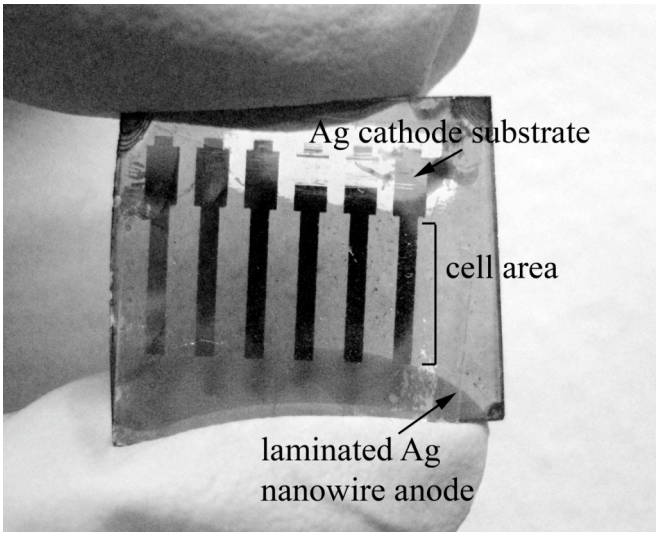

Fig. 1 Photograph of organic bulk heterojunction photovoltaic cell on silver substrate with laminated nanowire electrode.

Figure 2 shows the energy levels of the components of the fabricated cell. This shows clearly the inverted geometry, as light enters through the nanowires, which, along with the PEDOT:PSS, serve as the hole-collecting anode. The open-circuit voltage from the energy level diagram is expected to be around 0.4 V, whereas the actual open circuit voltage varied between 0.31 V and 0.33 V in fabricated devices. This is likely the result of non-ideal values for the workfunctions of the PEDOT:PSS and nanowire electrodes.

The current-voltage characteristics of the device in the dark and under illumination are shown in figure 3. There is a clear photocurrent generation occurring in this cell, resulting in an open circuit voltage of 0.3 V, and a short circuit

current density of 0.4 mA/cm^2. There are also some clear performance problems as well. The device has a high shunt resistance and poor fill factor. Future work will focus on improving all of these device properties.

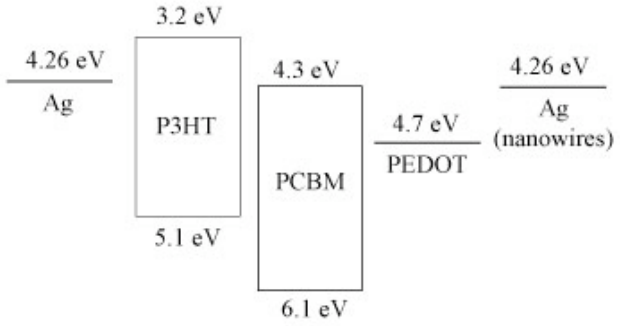

Fig. 2 Energy levels for organic bulk heterojunction photovoltaic cells fabricated in this work. The P3HT and PCBM were blended together in a 1:0.8 ratio to form one active layer film.

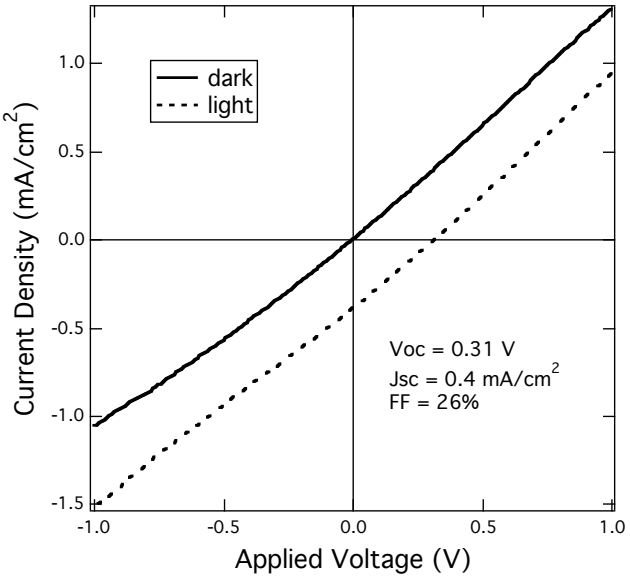

Fig. 3 Current-voltage curves in the dark (solid) and illuminated (dashed) for the device structure Ag/P3HT:PCBM/PEDOT:PSS/Ag nanowires. Inset: device performance characteristics.

4. Discussion and Conclusions

While the device characteristics of the inverted entirely solution-processed photovoltaic cells on silver foil substrates are not at the level of the best organic photovoltaic cells, the initial findings are promising and the concept has been proven here. No layer except the substrate, which could eventually be replaced by an aluminum foil with a thin electrodeposited silver layer, was deposited using a vacuum process. The entire device could eventually be fabricated entirely using solution roll-to-roll techniques and lamination at atmospheric pressure.

In future work, the open circuit voltage could most likely be improved by modifying the interface between the silver and the active layer to increase the work function difference between the silver foil and the PEDOT. This could also improve both the fill factor and the short circuit current as well. In addition, optimizing the morphology of the active layer through either annealing [8] or solvent annealing [9] has been shown to increase both short circuit and fill factor, and neither process has been used in these cells. In addition, the metal foil substrate offers an easy and low-cost way to obtain substrate texturing, such as a v-shape [10], to enhance light trapping in the cell. This texturing could eventually bring the efficiency of an organic photovoltaic cell on a metal foil substrate higher than a comparable flat cell on a transparent conductive substrate like ITO.

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