Extended Abstracts of the 2008 International Conference on Solid State Devices and Materials, Tsukuba, 2008, pp. 324-325

I-3-1

Semitransparent Organic Photovoltaic Cells with Laminated Top Electrode

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1. Introduction

Organic photovoltaic cells are considered a promising solar cell technology because of a potential for low-cost production, compatibility with flexible substrates, and environmental stability. Due to relatively short diffusion lengths of excitons in organic materials, the thickness of active layer needs to be rather thin (~100nm) to ensure efficient exciton dissociation at the donor-acceptor junction. Therefore, devices without the usual reflective metal cathode layer can have a high optical transmissivity, making such organic photovoltaic cells attractive for applications in semitransparent power-generating coatings, if appropriate transparent conductor materials are provided. Recently, a laminated transparent polymer cathode on top of polymer photovoltaic cells was reported [1], but the device performance was poor due to the very low conductivity of the cathode layer. Sputtered indium-tin-oxide (ITO) transparent cathode layers have been also reported [2,3]. However, the slow and expensive sputtering process used is not appropriate for high throughput roll-to-roll process. Moreover, the sputtering process is known to incur damage to the organic active layer. Here, we demonstrate transparent organic photovoltaic cells laminated with silver nanowire meshes functioning as the cathode layer. As we reported earlier, silver nanowire meshes are as transparent as sputter-coated ITO at the same sheet resistance [4]. The low-cost process and fast processing of such silver nanowire meshes makes them suitable for large area applications and roll-to-roll processing.

The silver nanowire meshes can also be used as an excellent contact between adjacent cells in multijunction structures [5] to achieve higher efficiencies. The ability to extract photocurrent laterally from the multijunction cells would allow one to achieved greater efficiencies since one is no longer limited by the cell producing the lowest photocurrent as is the case for a series-connected multijunction cell [5].

Here, we report on a process to laminate transparent silver nanowire mesh electrodes on top of an organic solar cell without any deleterious effect on the active layers.

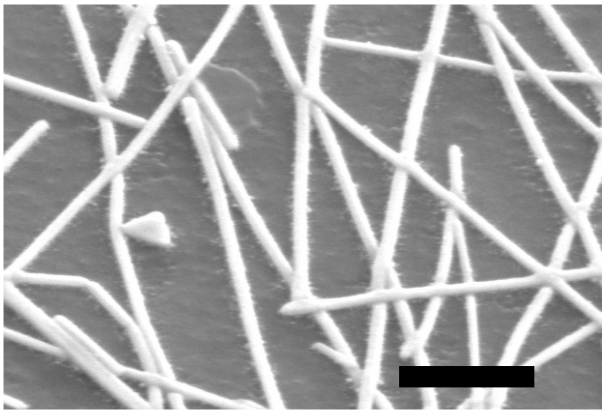

Fig 1. Scanning electron microscopy(SEM) image of the transparent organic photovoltaic cell. bathocuproine (BCP) layer and silver nanowires are seen. Black bar: 500nm scale.

2. Experimental Details

Silver nanowires(NWs) are prepared on a pre-cleaned glass substrate as described in previous work [4]. Subsequently, these nanowire meshes are pressed (~10^4 psi) with a clean glass substrate using a hydraulic press for the purpose of flattening any roughness. As a result, the silver nanowires are fused together, possibly leading to improved electrical connections between the nanowires. The organic materials are grown on pre-cleaned ITO-coated glass with the last layer being a 3nm-thick silver layer, after which the nanowire meshes are laminated onto the active organic layers by applying pressure. The silver nanowires transfer completely from the donor glass substrate to the organic solar cell because of the 3nm silver stiction layer. Figure 1 shows a scanning electron microscope (SEM) image of the top layer of the transparent organic photovoltaic cell. It is clear that lamination process ensures a good contact between the silver nanowires and the top organic layer. The device structure is ITO / copper phthalocyanine (CuPc) (25nm) / C_{60} (50nm) / bathocuproine (BCP) / Ag (3nm) / silver nanowire mesh. Control devices with a vacuum-deposited 100nm-thick silver cathode were deposited on another substrates. The fabricated photovoltaic cells were characterized in the dark and under AM1.5G solar illumination. Transmittance measurements were performed with a Varian Cary 6000i spectrophotometer.

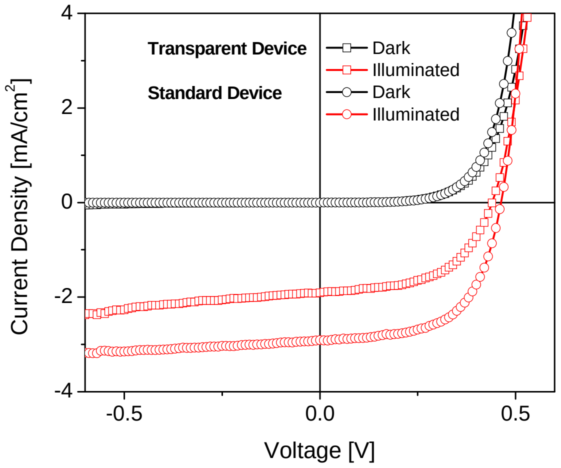

Fig 2. Current-Voltage characteristics for both transparent photovoltaic cell (open squares), and conventional cell (open circles).

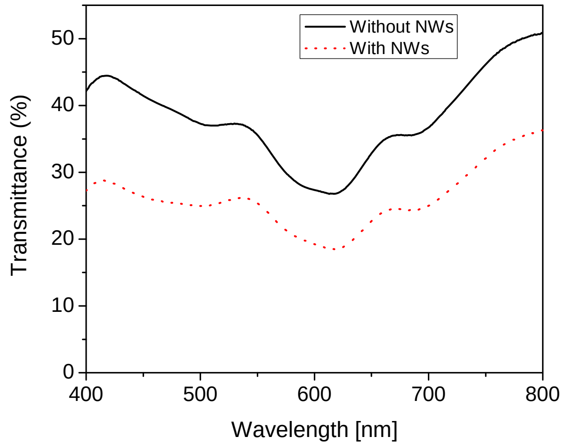

Fig 3. Transmission spectra for photovoltaic cells with silver nanowires (dotted line), and without silver nanowires (solid line).

3. Results and Discussion

Under 73mW/cm^2 AM1.5G illumination, the transparent cell exhibits a power conversion efficiency (PCE) of 0.63%, an open circuit voltage of V_{oc}=0.44V, a short-circuit current of J_{sc}=1.91mA/cm^2, and a fill factor of FF=0.55. For comparison, for the opaque control device we obtain PCE=1.1%, V_{oc}=0.46V, J_{sc}=2.91mA/cm^2, FF=0.60. The current-voltage characteristics of both a semitransparent organic photovoltaic cell and a conventional opaque cell are shown in Figure 2. The higher efficiencies of the conventional devices can be attributed to enhanced optical absorption due to the incident light passing twice through the active layer and optical interference effects by virtue of the reflective cathode. Figure 3 shows transmittance data of the semitransparent organic photovoltaic cells. The averaged transmittance over the spectral range 400nm-800nm is 26%. Only specularly transmitted photons were collected for the measurements. However, since approximately 20% of transmitted photons will be scattered by the silver nanowire mesh, the diffuse transmittance is likely higher.

4. Conclusions

We have demonstrated semitransparent organic photovoltaic cells with laminated silver nanowire meshes as a transparent, high-performance cathode layer. A power conversion efficiency of 0.63% under simulated AM1.5G illumination and 26% average optical transmittance were shown. These results suggest that semitransparent organic photovoltaic cells using silver nanowires meshes as the transparent cathode can be used to tint window glass while generating electric power. Moreover, tandem structures with highly conductive and transparent metal nanowires are now possible and may lead to very high efficiency organic multijunction photovoltaic cells with parallel cell connections.

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