

Single Donor-Acceptor Heterojunction Organic Photovoltaic Cell with an AgO-Based Anode

Chiu-Sheng Ho¹, Wei-Chou Hsu¹, Ching-Sung Lee², Ke-Hsin Hsiao¹, and Wen-Hsuan Lai¹

¹Institute of Microelectronics, Department of Electrical Engineering, National Cheng Kung University
Advanced Optoelectronic Technology Center, National Cheng Kung University
1 University Road, Tainan, Taiwan 70101, R.O.C.

Phone: +886-6-2757575 #62350 E-mail: wchsu@eembox.ncku.edu.tw

²Department of Electronic Engineering, ICEMC Center, Feng Chia University
100 Wenhwa Road, Taichung, Taiwan 40724, R.O.C.

1. Introduction

Organic thin film organic photovoltaic (OPV) cells have the potential advantages of light weight, large area fabrication low-cost flexible substrates, and being suitable for roll-to-roll processing [1-3]. The development of OPV cell starts from the single-layer homojunction structure with low generation current and power conversion efficiency (PCE). Then, the electron donor-acceptor heterojunction, i.e., bilayer structure [4-5], bulk heterojunction (BHJ) [6], p-i-n type structures were studied to improve the efficiency performance. Most organic devices utilizes the indium tin oxide (ITO) as the anode electrode. However, many shortcomings with ITO have been indicated recently. It is more expensive, requires complex fabrication equipment, and toxic in nature, chemical instability. It also mismatches with the highest occupied molecular orbital (HOMO) of the organic electron donor material, like copper phthalocyanine (CuPc). Therefore, more suitable anode materials need to be investigated for the OPV cells.

This work presents using silver oxide as the anode electrode in a single donor-acceptor heterojunction OPV cells. The CuPc and fullerene (C60) are used as electron donor and electron acceptor materials, respectively, of the active layers. The silver oxide provides great potential to replace ITO anode, such as having suitable work function with the HOMO of CuPc [7], low resistivity, and low series resistance characteristics.

2. Device Structure and Fabrication

First, glass substrate is cleaned with organic solvents by rinsing 5 minutes in the ultrasonic bath. Then, it is baked at 120°C for 20 minutes in the drying oven. Patterned 15 nm-thick Ag was formed as the anode upon the glass substrate by using high-vacuum thermo evaporation. Its sheet resistance is characterized to be 4.23Ω/square. Different kinds of oxidation treatments for Ag-anode were performed. In comparison, an ITO-anode with sheet resistance of 9.96 Ω/square was prepared. A 30 nm-thick CuPc layer is deposited on anode to serve as the electron donor layer. A 40 nm-thick C60 layer as the electron acceptor layer and a 10 nm-thick 2,9-dimethyl-4,7-diphenyl-1,10-phenanthroline (BCP) layer as the exciton blocking layer, are then deposited on the

CuPc layer. Finally, a 100 nm-thick Al layer is deposited as the cathode. The schematic cross section of the studied OPV cell is shown as Fig. 1.

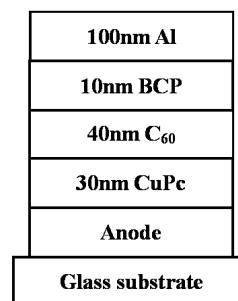


Fig. 1 Schematic cross section of the studied OPV cell.

We demonstrated five kinds of oxidation treatments on the Ag anode, including the UV-ozone method, immersing in a hydrogen peroxide solution, heating under oxygen atmosphere in PECVD, the oxygen plasma treatment in PECVD, and the ozone water treatment. Different treatment conditions, such as varying the heating temperature, oxidized time, solution concentration, and DC power in PECVD, have been tried on a 15 nm-thick Ag anode.

All organic materials used are not further purified, and all measurements in this work are in a nitrogen atmosphere glove box to reduce the effects of humidity. The photo-current density characteristic is measured by using an AM 1.5 simulation solar light source correlated with a Keithley 2400 source meter. The current density is defined by the active area of 0.09 cm². Related absorption and transmittance spectra of organic materials and anode electrodes are determined by using an Ocean Optics USB4000 spectrometer calibrated with an LS-1-CAL standard source. The sheet resistance, work function, and morphology on surface of thin films have been measured by using the four-point probe with a Model 280 CI in the Auto Mapping system, the ultraviolet photoelectron spectroscopy (UPS), and the Atomic Force Microscope (AFM) P7LS system, respectively.

3. Experimental Results and Discussions

Figure 2 shows the absorption spectra of the active layers (30 nm CuPc/40 nm C60/10 nm BCP) in our devices

and the transmittance spectra of the ITO and 15 nm-thick Ag anode. The transmittance of 15 nm-thick Ag within wavelengths of 400-700 nm wavelength is about 70%, which is lower than that of ITO of about 91%. However, the amount of generating excitons was reduced in the C60 layer wavelengths of 400-500 nm, owing to higher absorbance on the Ag anode. Comparing the performance under 100 mW/cm² illumination for both ITO- and Ag-based OPV cells as shown in Table I, the results indicate that V_{oc} , J_{sc} , FF, and PCE values are decreased in the those cells with the AgO anode. Lower V_{oc} results from larger reverse-bias leakage current densities. Lower J_{sc} results from higher barrier of the hole transportation, owing to the difference in work function for ITO and Ag. The root mean square (RMS) roughnesses are 2.97 nm and 1.68 nm for the AgO and ITO electrodes, respectively. Although lower sheet resistance of AgO makes the lower series resistance of device. The FF of AgO-based device is lower than that of ITO-based device, owing to its lower shunt resistance of 43 Ω /square than 7020 Ω /square of the ITO-device. The above results show that the AgO-based device show lower PCE of 0.34% than 1.05% of the ITO-based device under 100mW/cm².

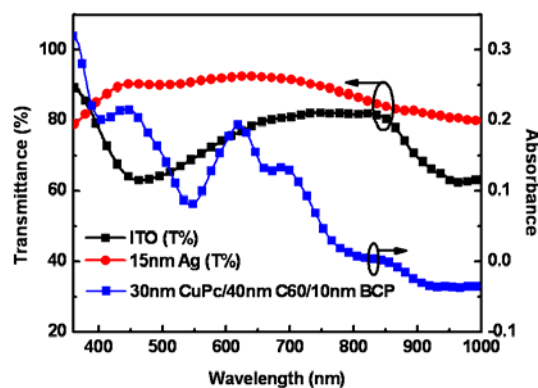


Fig. 2 Absorption and transmittance spectra of active layers and anode in devices.

Table I shows the characterized results for different AgO oxidation treatments. For the UV-ozone treatment, the treatment time varies from 5 to 40 seconds. The AgO-device with the treatment time of about 10 seconds shows the highest transmittance of 61.7%, and the lowest RMS roughness of 2.65 nm. For the treatment of immersing in a hydrogen peroxide solution, various concentrations were studied. Immersing in a 1:70 ratio of hydrogen peroxide and D.I. water for 5 seconds for AgO-device shows the best performance. Different heating temperatures in the PECVD under oxygen atmosphere have also been tried. The device treated at 125°C for 15 seconds shows the best performance. Oxygen plasma was used to oxidize the Ag anode to increase the work function of silver oxide in top-emitting organic light-emitting diode (TEOLED) [7]. Therefore, we have varied the RF power to treat our sample. The highest transmittance of 75.1% is obtained with RF power of 1 W for 30 seconds. Finally, the saturated ozone water method was used to oxidize Ag. The oxidation

system includes a Welsbach T-816 ozone generator with D.I. water solution, which operated at room temperature under the atmospheric pressure. The sample was immersed in an ozone water with various time, including 2, 4, 6, 8, and 10 seconds. The best PCE of 0.99% was obtained in a 6-sec treatment. Besides, J_{sc} is 4.23 mA/cm², RMS roughness is 3.46 nm, and the work function is 4.78 eV, respectively, as shown in Table I.

Table I Performance compared with different treatment of our studied devices.

| Anode / treatment method | V_{oc} (V) | J_{sc} (mA/cm ²) | FF | η (%) |
|--|--------------|--------------------------------|------|------------|
| ITO / without treatment | 0.4 | 4.34 | 0.6 | 1.05 |
| Ag / without treatment | 0.3 | 2.49 | 0.46 | 0.34 |
| Ag / UV-Ozone | 0.4 | 2.95 | 0.53 | 0.62 |
| Ag / H ₂ O ₂ :H ₂ O | 0.4 | 3.55 | 0.57 | 0.81 |
| Ag / PECVD + O ₂ + heating | 0.4 | 3.64 | 0.58 | 0.84 |
| Ag / O ₂ Plasma | 0.4 | 3.92 | 0.56 | 0.88 |
| Ag / Ozone water | 0.4 | 4.23 | 0.58 | 0.99 |

4. Conclusion

In this work, we demonstrate using an AgO anode for an OPV cell with single donor-acceptor heterojunction structure. Different oxidation treatments with varied processing conditions were conducted. The results showed promising potential of AgO to replace ITO film as the anode electrode for the OPC cells.

Acknowledgements

This work was supported by the National Science Council of the Republic of China under contract no. NSC 97-2221-E-006-240-MY3.

References

- [1] D. Wohrle and D. Meissner, *Adv. Mater.* **3** (1991) 129
- [2] H. Hoppe and N. S. Sariciftci, *J. Mater. Res.* **19** (2004) 1924
- [3] C. Waldauf, M. C. Scharber, P. Schilinsky, J. A. Hauch, and C. J. Brabec, *J. Appl. Phys.* **99** (2006) 104503
- [4] C. W. Tang, *Appl. Phys. Lett.* **48** (1986) 83
- [5] P. Peumans, V. Bulovi and S. R. Forrest, *Appl. Phys. Lett.* **76** (2000) 2650
- [6] P. Sullivan, S. Heutz, S. M. Schultes, and T.S. Jones, *Appl. Phys. Lett.* **84** (2004) 1210
- [7] K. Hong and J. L. Lee, *Elec. and Soli. Sta. Lett.* **11** (2008) H29