MASTER'S THESIS

Studies of efficient and stable organic solar cells based on aluminum-doped zine oxide transparent electrode

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Abstract

Organic solar cells (OSCs) have attracted significant attention due to their potential of large area solution fabrication capability at low-cost. For bulk heterojunction (BHJ) OSCs, a thin film of transparent conducting indium tin oxide (ITO), coated on glass or flexible plastic substrate, is widely used as a front electrode. However, indium is not abundant on Earth. Its price has increased continuously over the past 10 years and will likely become an obstacle for the commercialization of OSCs at low cost. Aluminum-doped zinc oxide (AZO) is a promising ITO alternative due to its advantages of high electric conductivity, optical transparency, non-toxicity and low cost. However, reports on OSCs using AZO electrode are quite limited, due to the relatively lower power conversion efficiency (PCE) of AZO-based OCSs as compared to that of ITO-based OCSs.

This work focused on studies of high performance AZO-based OSCs through AZO surface modification, absorption enhancement and process optimization. The optical and electronic properties of AZO film including transmittance, sheet resistance, surface morphology and surface work function were characterized. AZO-based OSCs with conventional and inverted structures were fabricated. It was found that AZO-based OSCs with inverted structure demonstrated superior performance than the ones with conventional structure. The inverted structure avoids the use of acidic PEDOT:PSS hole transporting layer, allows the improving of the absorbance of the OSCs and therefore its efficiency.

An AZO front transparent cathode was used for application in high performance inverted BHJ OSCs. The photoactive layer consisted a blend of poly[[4,8-bis[(2-ethylhexyl)oxy] benzo [1,2-b:4,5-b'] dithiophene-2,6- diyl][3-fluoro- 2-[(2-ethylhexyl) carbonyl]thieno[3,4-b]thiophenediyl]](PTB7):3'H-Cyclopropa[8,25][5,6]fullerene-C70- D5h(6)-3'-butanoicacid, 3'-phenyl-, methyl ester ($PC_{70}BM$). A structurally identical control OSC having an ITO front cathode was also fabricated for comparison studies. The structure of OSCs was optimized to achieving absorption enhancement in

the active layer. AZO and ITO were modified with a 10 nm thick solution-processed ZnO interlayer to facilitate the efficient electron extraction. The results revealed that bilayer AZO/ZnO and the ITO/ZnO cathodes possess similar electron extraction property. AZO layer has a transparency cutoff at wavelength < 380 nm, results in a slight decrease in the short-circuit current density (J_{SC}). However, the decrease in J_{SC} is very small because the main energy of solar irradiation falls in the spectrum with wavelength > 380 nm. It shows that AZO-based OSCs have a promising PCE of 6.15%, which is slightly lower than that of a control ITO-based OSC (6.57%). AZO-based OSCs, however, demonstrate an obvious enhancement in the stability under an ultraviolet (UV)-assisted acceleration aging test. The significant enhancement in the stability of AZO-based OSCs arises from the tailored absorption of AZO electrode in wavelength < 380 nm, which serves as a UV filter to inhibit an inevitable degradation process in ITO-based OSCs due to the UV irradiation.

In order to further investigate the degradation mechanism of OSCs under UV exposure, the change in charge collection characteristics of the OSCs made with ITO/ZnO and AZO/ZnO front cathode before and after UV exposure was examined. It was found that there was an obvious decrease in the charge extraction efficiency of ITO-based OSCs after UV exposure, while there was no observable change in the charge extraction efficiency of OSCs made with AZO/ZnO cathode under the same acceleration aging test.

This work demonstrates that AZO is a suitable ITO alternative for application in OSCs, offering an improved device stability, comparable PCE and cell fabrication processes with an attractive commercial potential.

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List of Abbreviations

OSC	Organic solar cell
OPV	Organic photovoltaic
BHJ	Bulk heterojunction
TCO	Transparent conducting oxide
ITO	Indium tin oxide
AZO	Aluminum-doped zinc oxide
HTL	Hole transport layer
ETL	Electron transport layer
EEL	Electron extraction layer
PTB7	Poly[[4,8-bis[(2-ethylhexyl)oxy]benzo[1,2-b:4,5-b']dithiophene-2,6-diyl][3-fluoro-2-[(2-ethylhexyl)carbonyl]thieno[3,4-b]thiophenediyl]]
P3HT	Poly(3-hexylthiophene-2,5-diyl)
ICBA	Indene-C_{60} bisadduct
$PC_{70}BM$	3'H-Cyclopropa[8,25][5,6]fullerene-C_{70}-D5h(6)-3'-butanoicacid, 3'-phenyl-, methyl ester
$PC_{60}BM$	C_{60} derivative, [6,6]-phenyl-C_{61} -butyric acid methyl ester
PEDOT:PSS	Poly(3,4-ethylenedioxythiophene) poly(styrenesulfonate)
CB	Chlorobenzene
DIO	1, 8-Diiodooctane

HOMO	Highest occupied molecular orbital
LUMO	Lowest unoccupied molecular orbital
J–V	Current density–voltage characteristics
FF	Fill factor
V_{OC}	Open-circuit voltage
J_{SC}	Short-circuit current density
J_{ph}	Photocurrent density
V_{eff}	Effective voltage
PCE	Power conversion efficiency
IPCE	Incident photon-to-electron conversion efficiency
EQE	External quantum efficiency
VASE	Variable angle spectroscopic ellipsometry
n(λ)	Wavelength dependent refractive index
k(λ)	Wavelength dependent extinction coefficient
AFM	Atomic force microscopy
UPS	Ultraviolet photoelectron spectroscopy

Table of Contents: