FABRICATION AND CHARACTERIZATION OF HYBRID POLYMER SOLAR CELL

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ABSTRACT

The easy fabrication method, tunable physical and chemical properties and cost-effective fabrication process, makes organic solar cells (OSC) very attractive in photovoltaic application. Nonetheless, the device performance is limited due to the low charge mobility of the organic semiconductors that results in a less efficient of charge transport to the respective electrodes. In order to address such problems, hybrid polymer solar cells based on bulk heterojunction (BHJ) structure, which composed of a combination of both organic and inorganic semiconductors are employed. However, the BHJ device performances are strongly dependent on good processing conditions, especially enhancement of photons absorption as well as the improvement of charge transport properties. Hence, the involved parameters and properties should be well optimized.

This dissertation describes the study of effects of blend composition and types of acceptor materials used on the optical, structural, morphological as well as the electrical properties of the three different hybrid BHJ systems. The hybrid materials consist of a blend of p-type conjugated polymer of poly(3-hexylthiophene) (P3HT) and n-type inorganic metal oxide nanoparticles, namely, zinc oxide (ZnO), titanium dioxide (TiO_2) and yttrium oxide (Y_2O_3). The optical, structural and morphological characterizations of the blend thin films using UV-Visible absorption spectroscopy, X-ray diffraction (XRD) spectroscopy, Atomic Force Microscopy (AFM) and Field-effect Scanning Electron Microscopy (FESEM) are discussed. Furthermore, the co-relation of the thin film property with the device performance is presented. The results show that the device performance has been improved by optimizing the blend composition. This is due to an enhancement in light absorption in broader wavelength regime and improved charge transport through the formation of interpenetrating bicontinous pathway for the holes and electrons to reach the respective electrodes. These results are supported by the observation of the AFM and FESEM images of the increment in RMS roughness and formation of phase separation features in the blends. Besides, the well dispersion of inorganic nanoparticles over P3HT yields a larger interfacial area for charge carrier generation. Among the three hybrid systems investigated, P3HT:ZnO device performs the best with an optimal blend composition of 3% of ZnO nanoparticles in blend.

In order to further improve the device performances, ZnO sol-gel synthesis route has been utilized to produce a better mixing blend of P3HT and ZnO. Additionally, several approaches have been employed, namely modifying the sol content in blends, varying the annealing temperature, and inserting an additional ZnO buffer layer between the active layer and cathode. An optimal annealing treatment offers improved optical absorption properties and more uniform film surface morphology with eliminated redundant large pores and grain agglomerations. The role of the ZnO buffer layer in the blend system can be seen as an agent in facilitating the electron collection from the active layer to the cathode. The results indicate that the device efficiency has been improved by about 5 times for P3HT:ZnO sol gel device with optimized sol content (0.1ml sol), annealed at an optimized temperature of 100°C with additional ZnO buffer layer, compared to the P3HT:ZnO nanoparticles-based device.

ABSTRAK

Fabrikasi yang mudah, ciri-ciri fizikal dan kimia bolehlaras dan kos efektif proses fabrikasi, telah menyebabkan sel suria organik (OSC) amat menarik dalam bidang penggunaan fotovoltaik. Walau bagaimanapun, prestasi peranti menjadi terbatas disebabkan oleh kelincahan pembawa cas yang rendah bagi semikonduktor organik yang mengakibatkan angkutan cas ke elektrod menjadi kurang cekap. Dalam usaha untuk menangani masalah tersebut, sel suria polimer hibrid berasaskan struktur simpang-hetero pukal (BHJ) yang terdiri daripada kombinasi semikonduktor organik dan bukan organic telah digunapakai. Namun demikian, prestasi peranti amat bergantung kepada keadaan pemprosesan yang baik, terutamnya peningkatan serapan foton serta penambah-baikan sifat angkutan. Oleh yang demikian, parameter dan sifat yang terlibat perlu dioptimakan dengan sebaiknya.

Disertasi ini menerangkan kesan komposisi campuran dan jenis bahan penerima yang digunakan terhadap ciri-ciri optik, struktur, morfologi serta sifat elektrik bagi tiga sistem hybrid BHJ berbeza. Bahan hybrid terdiri daripada campuran bahan jenis-p polimer berkonjugat (3-hexylthiophene) (P3HT) dan bahan jenis-n nanopartikel oksida logam bukan organik, iaitu zink oksida (ZnO), titanium dioksida (TiO_2) dan yttrium oksida (Y_2O_3). Pencirian optik, struktur dan morfologi dibincangkan bagi filem nipis campuran yang menggunakan spektroskopi serapan ultraungu-cahaya-nampak (UV-Vis), spektroskopi belauan sinar-X (XRD), mikroskop daya atom (AFM) dan mikroskopi electron daya imbasan (FESEM). Malahan, hubung-kait antara sifat filem nipis dengan prestasi peranti juga dibentangkan. Dapatan kajian menunjukkan bahawa prestasi peranti telah ditingkatkan dengan mengoptimumkan komposisi campuran. Ini disebabkan oleh peningkatan dalam penyerapan cahaya di rantau gelombang yang lebih luas dan meningkatnya angkutan cas melalui pembentukan laluan dwi-berterusan saling-menyusup untuk pergerakan lohong dan electron sampai ke elektrod. Hasil ini disokong oleh pemerhatian terhadap imej AFM and FESEM yang mana terdapat kenaikan dalam nilai kekasaran RMS dan pembentukan pemisahan fasa dalam filem campuran. Selain itu, penyerakan nanopartikel bukan organik yang seragam dalam P3HT menghasilkan kawasan sempadan antara-fasa yang lebih luas untuk menjana pembawa cas. Antara tiga jenis sistem hybrid yang dikaji, peranti P3HT:ZnO memberikan prestasi terbaik dengan 3% nanopartikel ZnO ke dalam komposisi campuran optimum.

Selanjutnya, sintesis sol-jel ZnO telah dijalankan bagi menghasilkan suatu campuran P3HT and ZnO yang lebih baik. Tambahan pula, beberapa pendekatan telah diambil, iaitu dengan mengubah isi kandungan sol dalam campuran, mempelbagaikan suhu pemanasan, dan memasukkan satu lapisan penampan ZnO di antara lapisan aktif dan katod. Rawatan pemanasan yang optimum menawarkan ciri-ciri penyerapan optik yang lebih baik dan permukaan morfologi filem yang lebih seragam dengan menghapuskan liang dan gumpalan besar. Peranan lapisan penampan ZnO dalam sistem campuran tersebut boleh dilihat sebagai suatu ejen yang memudahkan kutipan elektron dari lapisan aktif ke katod. Dapatan kajian ini menunjukkan bahawa prestasi bagi peranti berasaskan P3HT:sol-jel ZnO yang disediakan pada komposisi campuran (0.1 ml sol) dan suhu pemanasan optimum pada 100°C dan mengandungi satu lapisan penampan ZnO, telah meningkat sebanyak 5 kali ganda berbanding dengan peranti berasaskan P3HT:nanopartikel ZnO.

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LIST OF SYMBOLS

$>$	Less than
$<$	More than
π	Pi
σ	Sigma
T	Transmittance
A	Absorbance
I_o	Light intensities
E	Energy
λ	Wavelength
d	Interatomic spacing distance
θ	Diffraction angle
E_g	Energy gap
Δr	Bond length alternation
I_{SC}	Short-circuit current
V_{OC}	Open circuit voltage
P_{max}	Maximum power
P_{out}	Output power
V_{max}	Voltage at maximum power
I_{max}	Current at maximum power
P_{in}	Input power
FF	Fill factor
η	Power conversion efficiency
α	Absorption coefficient
t	Film thickness
B	Full width at half maximum
t_c	Crystallite size
C	Scherrer constant
ε	Strain
Λ_E	Exciton diffusion length
D_E	Exciton diffusion coefficient
τ_E	Exciton lifetime
R_a	Mean surface roughness
V_{on}	Turn-on voltage
J_{sc}	Short-circuit current density
R_{sh}	Shunt resistance
R_s	Series resistance
D/A	Donor/Acceptor
J-V	Current density-voltage
δ	Dislocation density
T_a	Annealing temperature

LISTS OF ABBREVIATIONS

BHJ	Bulk heterojunction
1-D	One dimensional
AFM	Atomic force microscopy
Ag	Silver
Al	Aluminum
AM 1.5	Air mass 1.5
Au	Gold
BL	Buffer layer
C_{60}	Buckminsterfullerene
Ca	Calcium
CB	Conduction band
CdSe	Cadmium selenide
$CHCl_3$	Chloroform
Cu	Copper
DEA	Diethanolamine
EDX	X-ray spectroscopy
FESEM	Field-effect scanning electron microscopy
FWHM	Full width at half maximum
HCl	Hydrochloric acid
HE	High energy
HOMO	Highest occupied molecular orbital
ITO	Indium tin oxide
JCPDS	Joint committee on powder diffraction standards
LE	Low energy
LUMO	Lowest unoccupied molecular orbital
MEH-PPV	Poly[2-methoxy-5-(2'-ethylhexyloxy)-p-phenylene vinylene]
MgPh	Magnesium phthalocyanine
NPs	Nanoparticles
OSCs	Organic solar cells
P3HT	Poly(3-hexylthiophene)
PbS	Plumbum sulfide
PCBM.	[6,6]-phenyl-C_{61}-butyric acid methyl ester
PCE	Power conversion efficiency
PEDOT:PSS	Poly(3,4-ethylenedioxythiophene) poly(styrenesulfonate)
PPP	Poly-para-phenylene
PT	Poly(thiophene)
PV	Photovoltaic
RMS	Root-mean-square
rpm	Rotations per minute
SMU	Source measuring unit
STC	Standard test condition
TiO_2	Titanium dioxide
UV-VIS-NIR	Ultraviolet-visible-near-infrared
VB	valence band
XRD	X-ray diffraction
ZnO	Zinc oxide