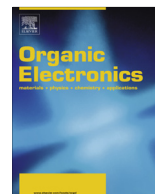




ELSEVIER

Contents lists available at ScienceDirect

Organic Electronics

journal homepage: www.elsevier.com/locate/orgel

Vacuum deposited ternary mixture organic solar cells



Graeme Williams*, Hany Aziz

Department of Electrical and Computer Engineering & Waterloo Institute for Nanotechnology, University of Waterloo, 200 University Avenue, Waterloo, ON N2L 3G1, Canada

ARTICLE INFO

Article history:

Received 27 October 2014

Received in revised form 2 December 2014

Accepted 13 December 2014

Available online 24 December 2014

Keywords:

Organic solar cell

Ternary

Vacuum deposition

Small molecule

Transient photocurrent

ABSTRACT

Ternary mixtures of photo-active organic materials are an intuitive approach to achieve enhanced photocurrent in organic solar cells (OSCs). In this work, we study ternary mixtures of vacuum deposited small molecules, complementing the recent surge of interest in solution processed ternary OSCs. The mixed layer composition is systematically varied to study all possible film configurations, and the resulting OSCs are successful in harvesting photocurrent from all three components to grant broad spectral photoresponse. However, the performance of the ternary OSC is generally less than the binary OSC, largely due to reduced fill factors. By examining ternary OSC transient photocurrents and multi-donor planar heterojunction devices, we demonstrate that the ternary OSC is strongly affected by the energy levels of its constituent materials, with small differences in the two donor materials' highest occupied molecular orbitals degrading hole transport. The results stress the importance of fine molecular engineering for ternary OSCs, and further hint that the enhancements commonly observed in solution processed ternary OSCs may in part be associated with morphological variations that are not present in vacuum deposited OSCs. The research verifies that, by designing small molecules with specific energy levels, ternary OSCs provide an alternative pathway to low cost, high efficiency photovoltaics in lieu of more complicated device architectures.

© 2014 Elsevier B.V. All rights reserved.

1. Introduction

The intensive research efforts on organic solar cells (OSCs) have generated a vast number of opto-electronic organic materials with varied absorption and charge transport properties. These materials developments have allowed for substantial improvements in the efficiencies of single junction OSCs in the past decade, from the landmark 5% efficient OSCs in 2005 [1–3], up to the 8–9% efficient OSCs established more recently [4–6]. Unfortunately, these organic materials are limited by their relatively narrow absorption bands, at least compared to the broad absorption of silicon used in first generation solar

cells. Following this realization, the logical approach for bolstering OSC performance in literature has been to employ more than one primary absorber. The simplest method is to use a C₇₀ fullerene acceptor instead of the traditional C₆₀ fullerene acceptor (analogously, PC₇₀BM versus PC₆₀BM). Given C₇₀'s stronger visible absorption properties compared to C₆₀, this method allows both the donor and the acceptor to absorb light and generate meaningful photocurrent [7–9]. Unfortunately, even with C₇₀, the breadth of absorption in OSCs is unsatisfactory compared to silicon, and the substantially increased costs of C₇₀ make it impractical for manufacturing scale-up. Non-fullerene acceptors have also been investigated, but generally have lower efficiencies [10–13]. As a consequence, many researchers have shifted their focus toward alternative device structures that allow for more than two primary absorbers, such as the tandem solar cell approach that

* Corresponding author.

E-mail address: g3willia@uwaterloo.ca (G. Williams).

has granted 11–12% OSCs [14–16], and the more recently studied ternary OSC.

OSCs are classified as second generation photovoltaics, which comprise thin-film solar cells that aim to compete with first-generation silicon photovoltaics on their price point. This is primarily accomplished by substantially reduced materials costs, but also requires relatively simple device structures for ease of fabrication (e.g. through reel-to-reel methods). As such, while the tandem OSC can grant impressive efficiencies, its use of 10–15 individual layers – each requiring optimization of highly controlled fabrication recipes – makes it a difficult structure to implement in practical OSCs, especially in consideration of costs due to device complexity. A much simpler alternative to the tandem OSC is the ternary OSC, which has garnered significant interest in the past few years [17]. The ternary OSC makes use of a single photo-active layer: a bulk heterojunction (BHJ) comprised of three light-absorbing species to confer broader absorption than the standard binary BHJ. Researchers have examined ternary OSCs with multiple donors (more prevalent in literature) [18–26], as well as multiple acceptors [27–29]. Initial results have been positive, with most researchers demonstrating enhanced short circuit current densities (J_{sc}) due to broader spectral responses. Further, some ternary OSCs have been shown to have tunable open circuit voltages (V_{oc}) dependent on the composition of the mixed layer [30], instead of being pinned to the lowest V_{oc} dictated by the energy levels of the comprising donors/acceptors. The combination of enhanced J_{sc} and intermediate value V_{oc} can thus allow ternary OSCs to achieve reasonably high performances while greatly simplifying device fabrication.

To date, ternary OSCs in literature have been formed by solution coating methods, while vacuum deposited ternary OSCs have remained virtually unstudied. This is likely due to limitations with equipment (i.e. the need for multi-source evaporators), and the relative difficulty of simultaneously depositing three materials in a controlled manner. However, as the simultaneous deposition of three to four materials becomes more prevalent in white organic light-emitting diode (OLED) fabrication [31,32], it is also more accessible to OSC research. In this work, we study ternary OSCs comprised of a BHJ with two metal phthalocyanine donors and a C_{60} -fullerene acceptor, with the active layer deposited by vacuum deposition. Vacuum deposition is specifically employed to minimize concerns regarding morphology. To this end, in a solution-coated OSC, the choice of solvent/co-solvent for the 'ink' can have tremendous impact on the morphology of the film (especially with regard to phase separation), which has critical implications regarding device performance. It is therefore expected that the addition of an additional species to the ink, whether it is an extra donor or acceptor, will have drastic repercussions on the morphology and phase separation of the film (this is further suggested by recent research focusing on active layer morphology in ternary OSCs [33]). Furthermore, these alterations to morphology are likely present even when using a very small amount of the third photo-active species, considering that solvent additives can substantially impact device performance at very low concentrations [34–36]. For ternary OSCs, it is therefore

difficult to discriminate whether changes in photovoltaic parameters are solely due to the opto-electronic properties of the third component in the mixed layer, or related to changes in the morphology of the film. To this end, in the event that phase separation throughout the film changes considerably, direct comparisons of OSCs with and without the third component (binary versus ternary) may not be entirely valid. In contrast to solution processing, co-deposition by vacuum thermal evaporation (i.e. without substrate heating/post-processing steps) results in films that are inter-molecularly dispersed [37,38], with minimal phase separation. It follows that vacuum deposited ternary OSCs can provide a clearer understanding of the roles of the three components in the OSC, including a more robust knowledge of the impact of their fundamental opto-electronic properties. Therefore, vacuum deposited ternary OSCs provide a platform to study the impact of adding a third photo-active species, while minimizing concerns related to morphological variations that may otherwise obfuscate the data.

For the present study, we systematically vary the composition of the ternary mixture using a matrix approach, which allows us to study all possible and relevant mixing ratios. The results demonstrate that ternary mixed films can be used to generate photocurrent over the entire visible spectrum at wavelengths from 300 nm up to 800 nm. However, in all mixtures, the ternary OSCs have poorer FF values than equivalent binary (one-donor, one-acceptor) OSCs. The reduced performance is attributed to an offset in the highest occupied molecular orbital (HOMO) levels between the two donor materials, which ultimately results in hole trapping and poorer hole sweep-out to reduce the FF. The results suggest that the ideal alignment of energy levels is critical for ternary OSCs, and that the enhancements more commonly observed for solution processed ternary OSCs may in part be due to morphological changes (e.g. phase separation) associated with the addition of the third component to the BHJ. Nevertheless, with intelligent molecular design, ternary OSCs should allow for significant improvements in the J_{sc} of OSCs with minimal impact to other photovoltaic parameters, thereby providing a simple, cost-effective device structure.

2. Experimental

2.1. Device fabrication

To fabricate the devices, patterned ITO slides were first cleaned by successive sonication in acetone, Micro-90 surfactant and isopropyl alcohol. The slides were scrubbed with a cotton swab after the acetone and Micro-90 sonication steps. The slides were then placed in an oven at 100 °C for at least one hour but no longer than one day before use. The substrates were then treated with O_2 plasma in a Trion RIE/ICP system at 20 mTorr pressure and 100 W ICP power (flow rate of O_2 kept at 20 sccm). 5 nm of MoO_3 (Sigma Aldrich) was then deposited by thermal evaporation ($<5 \times 10^{-6}$ torr base pressure) at a rate of 0.5 Å/s. The organic materials were subsequently deposited by thermal evaporation. The mixed layers were fabricated by the

Download English Version:

<https://daneshyari.com/en/article/7701904>

Download Persian Version:

<https://daneshyari.com/article/7701904>

[Daneshyari.com](https://daneshyari.com)