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Published in:
Advanced Energy Materials

DOI:
10.1002/aenm.201802706

Publication date:
2018

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With power conversion efficiencies (PCEs) over 14% for single junction devices and over 17% for tandem devices, organic solar cells (OSCs) are on the road to commercial reality.

OSCs, a blend of carbon-based donor (D) and acceptor (A) materials, have environmental advantages compared with competing technologies. They do not contain toxic elements such as lead and cadmium. They have a short energy payback time (about half a year under typical sunlight conditions in northern Europe). They can be manufactured through low-cost printing technologies on flexible substrates. In addition, OSCs can be made into different colors and semitransparent or transparent, offering unique applications, e.g. for building integration.

In spite of these advantages, the PCEs of OSCs were, in the past, low, limiting their practical applications. The situation has now changed, with the emergence of OSCs based on non-fullerene acceptors during the past few years. Very recently, non-fullerene acceptors have resulted in record PCEs over 17% for tandem OSCs.

In this special issue, leading experts in the field are brought together, discussing key issues of OSCs, including materials design and processing, device engineering, device physics, and theoretical simulations. The articles in this issue not only summarize the recent development of these different topics, but also raise open questions that the community has yet to resolve.

As an early frontrunner in the development of donor polymers, poly (3-hexylthiophene) (P3HT) has made a significant contribution to the development of OSCs, especially in fullerene-based devices. Recently, P3HT has been also blended with non-fullerene acceptors. Though not with top efficiency, there is certainly a lot to learn from P3HT (McCulloch, Wadsworth, and co-workers). For acceptor materials, Hou, Yao, and Yu focus on non-fullerene acceptors for ternary devices. For fullerene-based ternary devices, the ratio of the third component was often low, due to the poor miscibility of the third component with the other two components. This problem has now been largely solved, because different non-fullerene acceptors that have similar building blocks in the conjugated backbone (and hence good miscibility between each other) can cover different absorption regimes and help to enhance the PCE. In addition to the efficiency, ternary devices might also benefit the device stability, especially the thermal stability. Müller and Zerio summarize the thermal stability and efficiency of D:A1:A2 ternary blends in terms of thermodynamic and kinetic arguments.

For binary devices, miscibility is of the same importance. Ade and co-workers highlight the significance of miscibility and its temperature dependence in understanding the morphology, performance, and stability of OSCs. Zhan, Wang, and Zhao present a practical review concerning how to control the morphology to optimize the device performance, in terms of molecular stacking, domain size, domain purity, and vertical phase separation. Another factor that can affect the morphology is the interlayer materials on which the active layer is deposited. Fang and co-workers review comprehensively the applications of small molecules as the interfacial materials in OSCs.

One reason that morphology influences the device performance is because it affects the charge-transfer (CT) states, which are believed to relate to both the short-circuit current and the open-circuit voltage of OSCs. Rand and co-workers focus specifically on the influence of morphology on the properties and behavior of interfacial D:A CT states. Another parameter that is key to device performance is the mobility, which can affect charge generation, recombination, and extraction (Neher, Stolterfoht, and Shoaee). Shuai, Yi, and Han review these processes at different time scales from a theoretical simulations perspective, emphasizing the importance of molecular packing structures. Riede, Banerji, Ramirez, and co-workers summarize key tradeoffs limiting the performance of OSCs: the tradeoff between the charge carrier generation efficiency and the open circuit voltage, and the tradeoff between device thickness and fill factor. Kirchartz and Rau aim to answer "what makes a good solar cell?", connecting fundamental material properties with a proper thermodynamic description of the device. A good solar cell certainly requires low photovoltage losses. Indeed, one of the main reasons why non-fullerene OSCs outperform fullerene-based OSCs is that the former has shown decreased photovoltage losses. In order to quantify the voltage losses, it is critically important to correctly determine the optical gap of OSCs (Gao, Kirchartz, Vandewal, and co-workers).

This special issue highlights some recent developments and progress reported at the OSC symposium at the European-Materials Research Society 2017 Spring Meeting. We are very grateful to all the authors for their commitment and the referees for their critical assessment of the work. We also thank the Advanced Energy Materials editors, especially Dr. Carolina Novo Da Silva, Dr. Aaron Brown, and Dr. Duoduo Liang, for their kind help and strong support.

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DOI: 10.1002/aenm.201802706