*energies*

*Editorial*

# Organic Solar Cells: From Fundamental to Application

**Yu Jiang [1], Youjun Bai [2,*] and Shenghao Wang [3,*]**

[1] Chengdu Product Quality Supervision, Inspection and Research Institute, Chengdu 610100, China
[2] School of Electromechanical and Automotive Engineering, Hainan College of Economics and Business, Haikou 571127, China
[3] Materials Gerome Institute, Shanghai University, Shanghai 200444, China
* Correspondence: 642baiyoujun@163.com (Y.B.); shenghaowang@shu.edu.cn (S.W.)

An organic solar cell (OSC) uses p-type and n-type organic layers sandwiched between a transparent electrode and a metallic electrode. OSCs have the advantage of providing feasible solution processed fabrication, low costs, color-tuning, and weight-light and flexible device fabrication. OSCs are, therefore, the emerging next-generation photovoltaic technology for sustainable energy harvesting. So far, bulk heterojunction (BHJ) OSCs have achieved tremendous progress with certified efficiency already over 18% [1]; this can be ascribed to the wisdom of chemical scientists who dedicatedly design and synthesize the desired organic materials (especially non-fullerene acceptors) which can utilize solar radiation to the greatest extent possible.

Although significant progress has been achieved, the application and commercialization of OSCs still lag behind other photovoltaic technologies (such as silicon solar cells). Fundamental research (such as manipulating morphology, controlling the phase separation, eliminating recombination possibilities, and regulating interfacial property) is required to further understand the factors affecting the device performance and synthesize new materials, which can further increase power conversion efficiency. When facing realistic applications, stability is a vital factor. Therefore, it is very important to develop the encapsulation method and assess the outdoor utilization performance. This Special Issue entitled “Organic solar cells: from fundamental to application” has collected eight papers published in *Energies*, which thoroughly concentrate on the abovementioned aspects. They bring important insights into the current progress of organic solar cell technology and provide useful information to further enhance the power conversion efficiency of OSCs and advance their real application.

Morphology is crucial for determining the photovoltaic performance of OSCs. In Ref. [2], entitled “Design of All-Small-Molecule Organic Solar Cells Approaching 14% Efficiency via Isometric Terminal Alkyl Chain Engineering”, Chen et al. introduce a simple terminal alkyl chain engineering process to fine-tune the active layer morphology of OSCs. Uniform phase separation and favorable combination for the face-on and edge-on molecular stacking of blended small-molecule donors (i.e., terminal alkyl chain engineering processed small molecules) and acceptors (Y6) formed a fluent 3D transport channel delivering high and balanced carrier mobilities and resulting in robust device performance (power conversion efficiency: ~14%). In Ref. [3], entitled “Branched Electron-Donor Core Effect in D-π-A Star-Shaped Small Molecules on Their Properties and Performance in Single-Component and Bulk-Heterojunction Organic Solar Cells”, Paraschuk et al. creatively synthesized two star-shaped molecules, before comparing them with four other reported star-sharped molecules. This study demonstrates the impact of the core type on the structure–properties relationship of star-shaped molecules, i.e., varying the type of electron-donor core that can control the solubility, thermal, optical, electrochemical properties, and photovoltaic properties of OSCs. Specifically, these two-novel star-shaped molecules showed better performance (compared to the other four) not only for single-component OSCs but also for BHJ OSCs. In Ref. [4], entitled “Recent Advances of Film–Forming Kinetics in Organic

check for updates

**Citation:** Jiang, Y.; Bai, Y.; Wang, S. Organic Solar Cells: From Fundamental to Application. *Energies* **2023**, *16*, 2262. https://doi.org/10.3390/en16052262

Received: 4 January 2023
Accepted: 5 January 2023
Published: 27 February 2023

Solar Cells", Liu et al. reviewed the relationship between the morphology of donor and acceptor domains and device performance. This review provides useful guidance on the viewpoint of film-forming kinetics for optimizing the OSC device performance.

Morphology is an explicit factor for OSCs. However, recombination is invisible and related to the dynamics and kinetics of carriers. A dramatic recombination quenches (or annihilates) the excitons (or free carriers), meaning the free carriers fail in their extraction to the external circuit. The recombination may exist either in interfaces or in bulk. Therefore, to improve the device performance, understanding the recombination mechanism in the device and finding strategies is vital to eliminate unfavorable recombination. In Ref. [5], entitled "Effects of Recombination Order on Open-Circuit Voltage Decay Measurements of Organic and Perovskite Solar Cells", Vollbrecht and Brus propose a model to reveal the non-geminate recombination in two BHJ OSCs, respectively. The charge carrier density, recombination rate, and recombination coefficient were determined. The proposed model, further validated by experiments, demonstrated a simple and effective method to reveal the recombination property of OSCs.

A transport material or interlayer (or buffer layer) between the active layer and electrodes (either between the active layer and cathode or the active layer and anode) is crucial for free carrier collection. In Ref. [6], entitled "Double Cathode Modification Improves Charge Transport and Stability of Organic Solar Cells", Lin et al. innovatively introduced a double cathode modification layer ($SnO_2$/ZnO) into non-fullerene OSCs. The double cathode buffer layer exhibits low recombination rates and high carrier mobility, making it beneficial to electron transport and collection. The champion device shows a ~13% power conversion efficiency: higher than single cathode layer ($SnO_2$ or ZnO) devices. Moreover, it can improve the device stability, proving the considerable potential of the double inorganic buffer layer and the importance of the buffer layer selection for high-performance OSCs. Along with the inorganic interlayer, an efficient organic interlayer was also exploited. In Ref. [7], entitled "An N-type Naphthalene Diimide Ionene Polymer as Cathode Interlayer for Organic Solar Cells", Kozma and Luzzati et al. successfully synthesized a naphthalene diimide-based cathode interlayer with a facile three-step reaction, for use as a cathode interlayer for both fullerene and non-fullerene OSCs. This cationic polyelectrolyte exhibited favorable solubility in alcohol solvents, transparency in the visible range, self-doping behavior, and good film-forming abilities. These properties allowed the increase in device performance, indicating the promising potential of organic cathode interlayers for high-performance OSCs. Note that in Refs. [6,7], although different materials (either inorganic or organic) were introduced, they remained valid and not contradictory. This is because different device structures and active materials were utilized in these studies. Actually, this is the merit of OSCs: the device structures and material selection are versatile to fit different fabrication methods with low costs and different realistic applications.

Stability is a fundamental challenge for the commercialization of OSC technology. Encapsulation, except for exploring stable materials, provides a complementary strategy to improve device stability. In Ref. [8], entitled "Study on the Enhanced Shelf Lifetime of CYTOP-Encapsulated Organic Solar Cells", Song and Lee et al. studied the effect of the hydrophobic cyclized transparent optical polymer (CYTOP) as a solution-processable encapsulation layer on the stability of OSCs. CYTOP utilization greatly enhanced OSCs' lifetime, i.e., a 4% decrease vs. 18% decrease in the initial performance. Furthermore, CYTOP encapsulation inhibits unfavorable changes in parasitic resistive components and trap-assisted recombination. These findings provide an inclusive perspective on the long-term lifetime issue and commercialization of OSCs.

Finally, when assessing the real application of OSC technology, outdoor verification is profoundly important because the long-term stability (such as photostability, air stability, and thermal stability) and material properties of OSCs differ significantly from other commercialized photovoltaic technologies. In Ref. [9], entitled "Outdoor Performance of Organic Photovoltaics: Comparative Analysis", Dolara et al. describe two outdoor experimental campaigns, comparing the operation of OSC modules with traditional photovoltaic modules—in particular, crystalline silicon and copper–indium–selenium—and assessing the OSC modules' power generation potential in vertical installations and under different conditions (i.e., equivalent to different solar radiation levels and different ambient temperatures). These works provide insights for researchers and engineers in the photovoltaic community on the benefits of OSC technology while providing hints on its commercialization.

**Author Contributions:** Writing—original draft preparation, Y.J.; writing—review and editing, S.W. and Y.B. All authors have read and agreed to the published version of the manuscript.

**Funding:** This work is supported by the Program for Professor of Special Appointment and Distinguished Professor (Eastern Scholar) at Shanghai Institutions of Higher Learning.

**Conflicts of Interest:** The authors declare no conflict of interest.

## References

1. Best Research-Cell Efficiencies. Available online: https://www.nrel.gov/pv/assets/pdfs/best-research-cell-efficiencies.pdf (accessed on 8 December 2022).
2. Chen, H.; Tang, H.; Hu, D.; Xiao, Y.; Fu, J.; Lv, J.; Yu, Q.; Xiao, Z.; Lu, X.; Hu, H.; et al. Design of All-Small-Molecule Organic Solar Cells Approaching 14% Efficiency via Isometric Terminal Alkyl Chain Engineering. *Energies* **2021**, *14*, 2505. [CrossRef]
3. Solodukhin, A.N.; Luponosov, Y.N.; Mannanov, A.L.; Savchenko, P.S.; Bakirov, A.V.; Shcherbina, M.A.; Chvalun, S.N.; Paraschuk, D.Y.; Ponomarenko, S.A. Branched Electron-Donor Core Effect in D-π-A Star-Shaped Small Molecules on Their Properties and Performance in Single-Component and Bulk-Heterojunction Organic Solar Cells. *Energies* **2021**, *14*, 3596. [CrossRef]
4. Liang, Q.; Yao, J.; Hu, Z.; Wei, P.; Lu, H.; Yin, Y.; Wang, K.; Liu, J. Recent Advances of Film–Forming Kinetics in Organic Solar Cells. *Energies* **2021**, *14*, 7604. [CrossRef]
5. Vollbrecht, J.; Brus, V.V. Effects of Recombination Order on Open-Circuit Voltage Decay Measurements of Organic and Perovskite Solar Cells. *Energies* **2021**, *14*, 4800. [CrossRef]
6. Lin, T.; Dai, T. Double Cathode Modification Improves Charge Transport and Stability of Organic Solar Cells. *Energies* **2022**, *15*, 7643. [CrossRef]
7. Sorrentino, R.; Penconi, M.; Andicsová-Eckstein, A.; Scavia, G.; Švajdlenková, H.; Kozma, E.; Luzzati, S. An N-type Naphthalene Diimide Ionene Polymer as Cathode Interlayer for Organic Solar Cells. *Energies* **2021**, *14*, 454. [CrossRef]
8. Kim, J.; Song, H.-J.; Lee, C. Study on the Enhanced Shelf Lifetime of CYTOP-Encapsulated Organic Solar Cells. *Energies* **2021**, *14*, 3993. [CrossRef]
9. Dolara, A.; Leva, S.; Manzolini, G.; Simonetti, R.; Trattenero, I. Outdoor Performance of Organic Photovoltaics: Comparative Analysis. *Energies* **2022**, *15*, 1620. [CrossRef]