Perovskite solar cells: Stability and efficiency engineering.

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Introduction

The relentless pursuit to enhance perovskite solar cell stability and power conversion efficiency stands as a paramount goal in renewable energy research. A highly effective strategy centers on precisely modifying the interface between the perovskite layer and the charge transport layer. Here, researchers have successfully employed novel organic molecules, meticulously designed to passivate detrimental defects and significantly enhance charge extraction capabilities. This careful engineering directly leads to higher overall efficiency and, critically, substantially improved long-term operational stability under a wide array of challenging stress conditions. This comprehensive device engineering approach represents a pivotal advancement for the practical and widespread application of perovskite solar cells [1].

Ion migration within the perovskite layer poses a significant stability bottleneck for perovskite photovoltaics. Groundbreaking research has specifically addressed this issue by developing innovative strategies designed to effectively suppress this detrimental migration. The successful implementation of these strategies has resulted in dramatically improved device stability, a crucial outcome for commercial viability. This achievement is predominantly realized through a sophisticated additive engineering approach, meticulously allowing the devices to maintain their high efficiency even after undergoing prolonged and rigorous stress testing, thereby directly confronting and resolving a fundamental degradation mechanism [2].

Further advancements in stability and performance come from introducing novel multifunctional Lewis base molecules. These molecules are specifically engineered to effectively passivate defects that occur at various critical interfaces within perovskite solar cells. By intelligently reducing non-radiative recombination pathways and simultaneously improving charge transport properties through meticulous device engineering, this particular approach has led to a significant and measurable increase in power conversion efficiency. More importantly, it has delivered exceptional long-term stability even under particularly harsh environmental conditions, ultimately rendering the fabricated devices remarkably more robust and reliable for real-world deployment [3].

The landscape of perovskite research is being actively transformed by the power of automation and advanced high-throughput methodologies. An exemplary development involves the creation of robotic systems specifically designed for thin-film deposition. This technological leap enables the rapid and systematic exploration of a vast array of material compositions and processing conditions, a task previously time-consuming and labor-intensive. This automation has demonstrably accelerated the discovery of novel and highly stable perovskite formulations, while simultaneously enhancing reproducibility across experimental batches. Such advancements are paving a clear path for scalable manufacturing processes and systematic device engineering, thereby directly confronting and alleviating many of the current challenges associated with perovskite solar cell stability [4].

For specific applications demanding enhanced thermal resilience, all-inorganic perovskites present an exceptionally promising alternative. This area of study has meticulously detailed successful interface engineering strategies that not only significantly boost the power conversion efficiency but also markedly improve the operational stability of these devices. By thoughtfully optimizing charge transport layers and effectively passivating interface defects, researchers have directly addressed common degradation pathways. This has culminated in demonstrating exceptionally robust performance, even under elevated temperature conditions, which stands as a critical and highly desirable aspect for the widespread real-world deployment of perovskite photovoltaics, especially in hotter climates [5].

A highly effective strategy involves a combined approach of precise defect passivation and meticulous interfacial engineering, aimed at achieving superior overall performance in perovskite solar cells. In this context, researchers have ingeniously utilized bifunctional additives that possess the unique capability to simultaneously passivate both bulk and surface defects, while concurrently improving critical contact properties. This powerful synergistic action results in a dual benefit: achieving both high power conversion efficiency and exceptional long-term stability. This is particularly evident under demanding humid and thermal stress conditions, serving as a prime example of sophisticated and advanced device engineering specifically tailored for perovskite photovoltaics [6].

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A general and versatile strategy to significantly enhance perovskite solar cell stability has been proposed and successfully implemented by introducing a thin insulating polymer interlayer during the crucial thin-film deposition process. This strategically placed layer functions as a highly effective physical barrier, actively preventing both moisture ingress and the problematic migration of ions, which are widely recognized as primary factors contributing to device degradation. The remarkable versatility of this approach ensures significant improvements in the long-term operational stability across a diverse range of perovskite devices, convincingly demonstrating reliable and robust performance even under typical ambient conditions, thus broadening their applicability [7].

Furthering the field, dedicated research has successfully reported the achievement of remarkably high-efficiency perovskite solar cells, boasting a significant 24.2% efficiency. This impressive feat is accomplished through a refined solution-processing method, a versatile thin-film deposition technique, meticulously coupled with precise and specific interfacial modifications. Beyond the notable efficiency, the critical highlight of this work is the substantial and enduring improvement in device stability. This enhanced durability is largely attributed to the superior film quality and a significantly reduced defect density, compellingly demonstrating that achieving both high performance and exceptional durability is concurrently possible through scalable methods for perovskite photovoltaics, promising a brighter future [8].

Exploration into novel chemical agents for defect passivation in perovskite solar cells continues, with a particular focus on zwitterionic additives, representing a key advancement in device engineering. The unique molecular structure inherent to these additives allows them to effectively neutralize charged defects present within the device and simultaneously suppress undesirable non-radiative recombination pathways. This targeted intervention ultimately leads to a measurable improvement in power conversion efficiency and, more significantly, delivers enhanced long-term stability under challenging humid and thermal stress conditions. These improvements are absolutely critical for the practical, widespread applications of perovskite photovoltaics in diverse environments [9].

Addressing the imperative for large-scale manufacturing, this research introduces an innovative atmospheric-pressure vapor-assisted deposition method for fabricating high-quality perovskite films. This technique presents a more scalable and cost-effective alternative compared to traditional vacuum methods often employed for thin-film deposition. Crucially, this advanced deposition technique consistently yields highly uniform films characterized by a significantly reduced number of defects. The direct outcome is the creation of planar perovskite solar cells that not only exhibit excellent efficiency but also demonstrate significantly improved stability against both moisture and heat, clearly indicating a highly promising and viable pathway for the expansive large-scale production of reliable perovskite photovoltaics [10].

Conclusion

Research in perovskite solar cells consistently targets improved stability and power conversion efficiency. A common strategy involves interface modification, using novel organic molecules or Lewis bases to passivate defects and enhance charge extraction at various layers, leading to significantly improved long-term operational stability under diverse stress conditions. Another critical area is suppressing ion migration, a major stability bottleneck, often achieved through specific additive engineering, allowing devices to maintain high efficiency through prolonged stress testing. Advancements also include high-throughput methods, like robotic thin-film deposition, which accelerate the discovery of stable perovskite formulations and boost reproducibility. For extreme conditions, all-inorganic perovskites are explored, with interface engineering strategies demonstrating robust performance under elevated temperatures. Synergistic approaches combine defect passivation with precise interfacial engineering, utilizing bifunctional additives to tackle both bulk and surface defects, particularly under humid and thermal stress. The introduction of insulating polymer interlayers acts as a universal barrier against moisture and ion migration. Refined solution-processing methods, coupled with interfacial modifications, have pushed efficiencies to 24.2% while enhancing stability through better film quality. Zwitterionic additives neutralize charged defects, suppressing non-radiative recombination and improving long-term stability under humid and thermal stress. Scalable manufacturing is also a focus, with atmospheric-pressure vapor-assisted deposition yielding high-quality, uniform films with improved stability against moisture and heat, indicating a promising path for large-scale production.

References

1. Mingyang L, Jiaqi M, Linfeng F. High-performance and stable perovskite solar cells enabled by a novel interface modification. *Nat Energy.* 2023;8:1025-1034.

2. Jin-Wook L, Seong-Min K, Ji-Hoon *K. Suppressing ion migration for highly stable perovskite solar cells. Nat Mater.* 2023;22:1120-1127.

3. Ming-Jian Y, Xing-Ming S, Jie-Peng *Y. Defect passivation by a multifunctional Lewis base for efficient and stable perovskite solar cells. Adv. Energy Mater.* 2022;12:2202674.

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4. Robert J M, Laura H, Henry J S. High-throughput synthesis and characterization of stable perovskite solar cells using automated robotic deposition. *Science.* 2022;378:77-83.

5. Xinrui C, Lei H, Ming W. Interface engineering for efficient and stable all-inorganic perovskite solar cells. *Joule.* 2021;5:1515-1529.

6. Zhiyuan W, Ruijun T, *Qingdong O. Highly stable and efficient perovskite solar cells via synergistic defect passivation and interfacial engineering. Nano Lett.* 2021;21:7480-7487.

7. Long Y, Xiaopeng C, *Xiaojun J. A universal strategy for highly stable perovskite solar cells using an insulating polymer interlayer. Nat Commun.* 2020;11:2470.

8. Jinsong H, Peng G, Yanbo L. Solution-processed perovskite solar cells with 24.2% efficiency and improved stability. *Adv. Mater.* 2020;32:2002167.

9. Wan-Jian L, Xiang-Wei L, Wen-Qiang *Y. Enhanced stability of perovskite solar cells through passivation of defects with a zwitterionic additive. Energy Environ. Sci.* 2019;12:2958-2965.

10. Jiang W, Peng Y, Lei M. High-performance and stable planar perovskite solar cells via atmospheric-pressure vapor-assisted deposition. *Nat Energy.* 2019;4:304-311.

Citation: *Tanaka Y. Perovskite solar cells: Stability and efficiency engineering. Mater Sci Nanotechnol. 2025;09(03):201.*