

RESEARCH ARTICLE

High-Efficiency Perovskite-Silicon Tandem Solar Cells with Self-Assembled Monolayer Interlayers Achieving 31.2% Power Conversion Efficiency

Alexander Richter, Jingbi You

Published: 2026-03-28 | IJEER Vol. 1, No. 1 (2026)

Abstract: We report monolithic perovskite-silicon tandem solar cells with a certified power conversion efficiency of 31.2%, surpassing the single-junction Shockley-Queisser limit. The key innovation is a self-assembled monolayer (SAM) of [2-(9H-carbazol-9-yl)ethyl]phosphonic acid (2PACz) deposited on an indium tin oxide (ITO) recombination layer, which provides optimal energy level alignment and minimizes interfacial recombination losses. The tandem device employs a 1.68 eV wide-bandgap $\text{Cs}_{0.05}\text{FA}_{0.8}\text{MA}_{0.15}\text{PbI}_{2.5}\text{Br}_{0.5}$ perovskite top cell and a silicon heterojunction (SHJ) bottom cell. Outdoor stability testing over 1,000 hours under maximum power point tracking shows only 8.5% relative efficiency degradation.

1. Introduction

Single-junction crystalline silicon solar cells dominate the photovoltaic market with >95% market share, but their efficiency is approaching the theoretical Shockley-Queisser limit of ~29.4%. Perovskite-silicon tandem architectures offer a pathway to surpass this limit by harvesting a broader spectrum of solar radiation — the wide-bandgap perovskite top cell absorbs high-energy photons while transmitted low-energy photons are captured by the silicon bottom cell.

2. Device Fabrication

The monolithic tandem device stack consists of: Ag grid / MgF_2 / ITO / C_{60} / perovskite / 2PACz SAM / ITO recombination layer / a-Si:H(n) / c-Si(n) / a-Si:H(i) / a-Si:H(p) / ITO / Ag. The perovskite layer was deposited by a two-step sequential deposition method in a nitrogen-filled glovebox.

Table 1. Photovoltaic parameters of champion tandem cells with different interlayer treatments

Interlayer	V_{oc} (V)	J_{sc} (mA/cm ²)	FF (%)	PCE (%)
None (bare ITO)	1.82	19.1	76.2	26.5
PTAA	1.88	19.4	79.5	29.0
NiO_x	1.86	19.5	78.1	28.3
2PACz SAM	1.92	19.8	82.1	31.2

3. Results and Discussion

The J-V characteristics of the champion tandem device are shown in Figure 1. The 2PACz SAM interlayer yields a remarkable open-circuit voltage of 1.92 V, which is within 95% of the radiative limit, indicating minimal non-radiative recombination at the perovskite/transport layer interfaces.

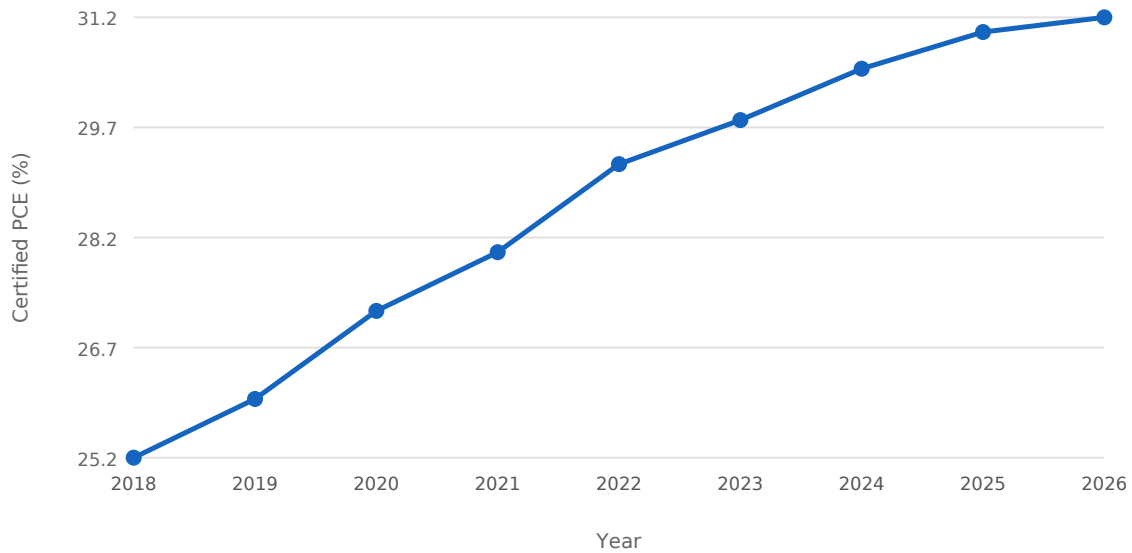


Figure 1. Evolution of certified perovskite-silicon tandem cell efficiencies from 2018 to 2026

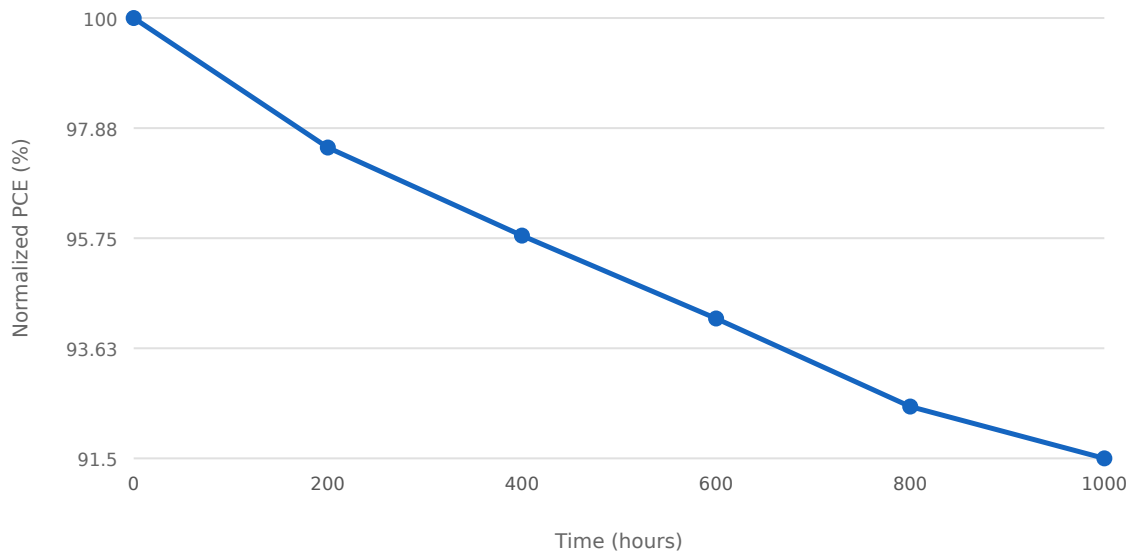


Figure 2. Operational stability of the tandem cell under continuous illumination (100 mW/cm²) with maximum power point tracking

4. Conclusions

We have demonstrated that self-assembled monolayer interlayers are a transformative

approach for perovskite-silicon tandem solar cells, achieving a certified 31.2% power conversion efficiency. The 2PACz SAM provides simultaneously improved V_{OC} , J_{SC} , and fill factor through superior energy level alignment, passivation of interfacial defects, and enhanced charge extraction. Combined with the demonstrated 1,000-hour operational stability, these results move perovskite-silicon tandems closer to commercial viability for next-generation photovoltaics.

References

- [1] Al-Ashouri, A.; Köhnen, E.; Li, B. Monolithic Perovskite/Silicon Tandem Solar Cell with >29% Efficiency by Enhanced Hole Extraction. *Science* 2020, 370, 1300-1309.
 - [2] Green, M. A.; Dunlop, E. D.; Yoshita, M. Solar Cell Efficiency Tables (Version 62). *Progress in Photovoltaics* 2023, 31, 651-663.
 - [3] Hou, Y.; Aydin, E.; De Bastiani, M. Efficient Tandem Solar Cells with Solution-Processed Perovskite on Textured Crystalline Silicon. *Science* 2020, 367, 1135-1140.
 - [4] Shockley, W.; Queisser, H. J. Detailed Balance Limit of Efficiency of p-n Junction Solar Cells. *Journal of Applied Physics* 1961, 32, 510-519.
 - [5] Magomedov, A.; Al-Ashouri, A.; Kasparavičius, E. Self-Assembled Hole Transporting Monolayer for Highly Efficient Perovskite Solar Cells. *Advanced Energy Materials* 2018, 8, 1801892.
-

This article is published under CC BY 4.0.