



Tin oxide as an electron transport layer in perovskite solar cells: Advances and challenges

Qamar Wali^{a,b}, Muhammad Aamir^{c,*}, Muhammad Ejaz Khan^d, Rajan Jose^e, Wei Fan^{a,f,*}, Shengyuan Yang^{a,*}

^a State Key Laboratory for Modification of Chemical Fibers and Polymer Materials, College of Materials Science and Engineering, Donghua University, Shanghai 201620, PR China

^b School of Applied Sciences & Humanities, National University of Technology, 44000 Islamabad, Pakistan

^c Materials Laboratory, Department of Chemistry, Mirpur University of Science and Technology (MUST), Mirpur-10250, (AJK), Pakistan

^d Computer Engineering Department, National University of Technology, 44000 Islamabad, Pakistan

^e Faculty of Industrial Sciences & Technology, Universiti Malaysia Pahang, Malaysia

^f Key Laboratory of Synthetic and Biological Colloids, Ministry of Education, School of Chemical and Material Engineering, International Joint Research Laboratory for Nano Energy Composites, Jiangnan University, Wuxi 214122, PR China

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ABSTRACT

Perovskite solar cells (PSCs) have appeared as a growing photovoltaic technology owing to their unprecedented performance compared to the market leader, silicon solar cells. The high efficiency (η) of 26 % within a decade brings hope for the photovoltaic community. However, their operational stability remains a critical issue and hinders their commercialization. Charge transport layers play a key role in the stability and overall performance of PSCs. While TiO_2 is the most common and successfully employed electron transport layer (ETL), it is neither a very efficient charge extractor at the interfaces nor stable under UV illumination. Alternatively, another promising ETL, such as SnO_2 , has recently emerged, producing remarkable performance in PSCs. The outstanding performance in SnO_2 -based ETL is owing to its extraordinary properties, such as its better band alignment with common perovskite material and higher mobility while being processable at low temperatures ($\sim 150^\circ\text{C}$). The best reported result with $\eta = 25.4\%$ for SnO_2 ETL has been achieved so far, comparable to that of the most employed ETL-based TiO_2 ($\eta = 26\%$). In this review, recent progresses in SnO_2 -based PSCs with η greater than 20 % and stability (>1000 h) are summarized together with a discussion on associated challenges and opportunities, with an emphasis on the road ahead for commercialization.

1. Introduction

Hybrid lead halide perovskite based solar cells (PSCs) have emerged as a promising class of solar cells, and their efficiency (η) has soared from 3.8 % to 26.0 % [17] merely in a decade, which has received widespread attention from both industrial and academic domains [28,37,38,76]. Despite its outstanding performance (η), there is still space for improvement compared to the theoretical Shockley Queisser limit of $\eta \sim 30\%$ for single-junction solar cells [91]. However, the long-term stability of PSC is the basic predicament in its commercialization [21,93,141]. The instability can be caused by intrinsic factors such as defects on the perovskite surface or at the interface, while moisture, oxygen, UV light, heat, etc., contribute toward the extrinsic instability

[14,25,113]. Although encapsulating the devices can protect against external factors, the intrinsic factors and mechanical stresses can still cause severe degradation [23,24,77,109,131]. Defects can lead to non-radiative recombination (NRR), ultimately lowering efficiency and stability loss. Hence, exploring strategies to suppress the NRR at various interfaces within the device is crucial. To ensure a stable and efficient PSC, minimizing the interfacial defects at the electron transport layer (ETL)-perovskite and hole transport layer (HTL)-perovskite interfaces is crucial. Studies have shown that the concentration of defect traps at the ETL/perovskite or perovskite/HTL interfaces or on the perovskite surface is far greater than the defect traps within the perovskite layer [46]. Generally, in PSCs, bulk crystal defects can be passivated using a suitable additive strategy, whereas the defects at the grain boundary and on the

* Corresponding authors at: State Key Laboratory for Modification of Chemical Fibers and Polymer Materials, College of Materials Science and Engineering, Donghua University, Shanghai. 201620, PR China (Wei Fan).

E-mail addresses: amir.chem@must.edu.pk (M. Aamir), weifan@dhu.edu.cn (W. Fan), cmseisy@dhu.edu.cn (S. Yang).

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