Perovskite Solar Cells

Modeling the Future of Renewable Energy

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ADVANCEMENTS AND CHALLENGES IN ALL-PEROVSKITE TANDEM SOLAR CELLS: A CRITICAL REVIEW

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Abstract

This comprehensive review article provides an in-depth examination of the recent advancements and limitations of all-perovskite tandem solar cells (AP-TSCs) with diverse configurations. Metal halide perovskites (MHPs) have garnered significant attention as a promising light absorber material in tandem photovoltaic devices, owing to their tunable bandgaps and robust light absorption capabilities across a broad spectral range of approximately 1.2-2.3 eV. Notwithstanding the remarkable progress achieved in this field, the power conversion efficiency (PCE) and stability of reported AP-TSCs remain inadequate for commercial applications, primarily due to the prevalence of defect activities in both the top wide bandgap (WB) and bottom narrow bandgap (NB) metal halide perovskites (MHPs). These defect activities lead to significant energy losses, thereby hindering the attainment of high PCE values. This article presents a critical examination of the distinct instabilities and energy loss channels inherent to WB-MHPs and NB-MHPs, as well as discusses corresponding strategies aimed at mitigating these issues. Furthermore, the impact of the interconnecting layer on the fabrication of high-quality light absorbers via solution-based methods is discussed. A detailed analysis of the unique requirements and methods for device packaging to enhance the stability of AP-TSCs is also provided. Ultimately, this review offers novel perspectives on the primary challenges, favourable circumstances, and heuristic outlooks for future research endeavours in the realm of AP-TSCs. By addressing the existing limitations and challenges, researchers can unlock the full potential of AP-TSCs, paving the way for the development of high-efficiency, stable, and commercially viable tandem solar cells.

Keywords: All-perovskite tandem solar cells, Metal halide perovskites, Power conversion efficiency, Stability, Defect activities, Energy loss channels, Interconnecting layer

1.1 Introduction

The escalating global energy demand, coupled with the depletion of fossil fuels, has intensified research efforts focused on harnessing renewable energy sources, such as solar, wind, and

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hydraulic power [1], [2]. Among these alternatives, solar energy has emerged as the most abundant and clean energy source, with the Earth receiving a staggering amount of solar energy that surpasses the total of all other energy types [3], [4]. Photovoltaics (PV) or solar cells have proven to be an effective means of generating electricity by converting photons into electrons directly. The first solar cells, developed by Bell Labs in the 1950s, utilized crystalline silicon. Subsequent research has led to the development of various PV materials, which can be categorized into three generations: (i) first-generation crystalline silicon solar cells, (ii) second-generation thin-film solar cells, and (iii) third-generation solar cells based on emerging materials. Metal halide perovskites (MHPs) have garnered significant attention in the realm of third-generation solar cells, with power conversion efficiencies (PCEs) surpassing 25% achieved through solution processing within a decade of active research [6], [7].

Perovskite solar cells (PSCs) have been hailed as a potential game-changer in photovoltaic technology, offering a promising route to cost-effective solar electricity generation in the future. The remarkable performance of MHP-based solar cells can be attributed to their extraordinary properties, including robust light absorption, long carrier diffusion lengths, high charge carrier mobility, and tuneable energy gaps. Theoretically, the Shockley-Queisser (SQ) radiative efficiency limit for single-junction PSCs with a medium bandgap ranging from approximately 1 to 1.5 eV is around 31% [8]. To surpass this limit, tandem solar cells (TSCs) have been proposed, wherein wide bandgap (WB) absorbers are stacked on top of narrow bandgap (NB) absorbers. This configuration enables the minimization of thermalization loss by harnessing high-energy photons in the front sub-cell and lower-energy photons in the rear sub-cell [9], [10]. TSCs comprising two sub-cells with MHPs having a bandgap of 1.25-1.8 eV can achieve a limiting PCE of approximately 42% [12]. The bandgap of MHPs can be widely tuned from about 1.2 eV to 3.0 eV by adjusting the combination of ions at each site of the lattice [13], [14]. Recent years have witnessed rapid developments in MHP-based TSCs, with reported efficiencies of 24.2% for MHP/CIGS TSCs, 32.5% for MHP/Si TSCs, and 29.0% for all-perovskite TSCs (AP-TSCs) [15], [16], [17]. AP-TSCs have emerged as a promising configuration due to their potential for low-temperature and cost-effective solution processing, compatible with mass-production techniques [19], [20]. Despite the advancements in AP-TSCs, their efficiency and stability remain inadequate for commercial requirements

Organic–inorganic perovskites have shown great promise for photovoltaics (PVs). Perovskite single junction solar cells have been recently certified at >26% efficiency close to established silicon at >27% efficiency. Moreover, certified perovskite-based tandem solar cells have made improvements in a short period of time from 4.6% in 2014 to the current world record of 33.9%. Even perovskite–perovskite–silicon triple junction solar cells have been recently reported with an efficiency of 27.1%. Recently, APTSCs have been gaining attention with rapidly increasing performances, with 28.5% (certified: 28.0%) efficiency for a perovskite–perovskite tandem (double junction). Although the efficiencies of APTSCs are still lower than silicon–perovskite tandems, they have several benefits.

This review aims to provide a comprehensive overview of the recent findings and strategies for addressing the instability and energy loss in AP-TSCs, offering an outlook for their future applications [21], [22].