



Perovskite Solar Cells

Modeling the Future
of Renewable Energy

Edited by Arthur James Swart,
Keshav Kumar, Bishwajeet Pandey
and Sakshi Sharma



CRC Press
Taylor & Francis Group

Designed cover image: Shutterstock

First edition published 2026

by CRC Press

2385 NW Executive Center Drive, Suite 320, Boca Raton FL 33431

and by CRC Press

4 Park Square, Milton Park, Abingdon, Oxon, OX14 4RN

CRC Press is an imprint of Taylor & Francis Group, LLC

© 2026 selection and editorial matter, Arthur James Swart, Keshav Kumar, Bishwajeet Pandey, and Sakshi Sharma; individual chapters, the contributors

Reasonable efforts have been made to publish reliable data and information, but the author and publisher cannot assume responsibility for the validity of all materials or the consequences of their use. The authors and publishers have attempted to trace the copyright holders of all material reproduced in this publication and apologize to copyright holders if permission to publish in this form has not been obtained. If any copyright material has not been acknowledged please write and let us know so we may rectify in any future reprint.

Except as permitted under U.S. Copyright Law, no part of this book may be reprinted, reproduced, transmitted, or utilized in any form by any electronic, mechanical, or other means, now known or hereafter invented, including photocopying, microfilming, and recording, or in any information storage or retrieval system, without written permission from the publishers.

For permission to photocopy or use material electronically from this work, access www.copyright.com or contact the Copyright Clearance Center, Inc. (CCC), 222 Rosewood Drive, Danvers, MA 01923, 978-750-8400. For works that are not available on CCC please contact mpkbookspermissions@tandf.co.uk

Trademark notice: Product or corporate names may be trademarks or registered trademarks and are used only for identification and explanation without intent to infringe.

ISBN: 9781032965031 (hbk)

ISBN: 9781032965055 (pbk)

ISBN: 9781003589747 (ebk)

DOI: 10.1201/9781003589747

Typeset in Sabon

by codeMantra

16 Thermal and power-efficient hardware design of solar panel on reconfigurable architecture	267
MAN MOHAN SHUKLA, KESHAV KUMAR, VIVEK KUMAR, AND BISHWAJEET PANDEY	
17 Solar charge controller design on FPGA	277
PREETI AGARWAL MITTAL, MOHIT KUMAR SRIVASTAVA, VAIBHAV PURWAR, VIVEK KUMAR, MAN MOHAN SHUKLA, AND KRISHAN KUMAR GARG	
18 Exploring the role of solar energy in advancing agricultural practices	301
ANKIT JAIN, ANITA SHUKLA, IMRAN ULLAH KHAN, AND PUSPRAJ SINGH CHAUHAN	
19 Machine learning in solar energy prediction	318
MOHIT KUMAR SRIVASTAVA, PREETI AGARWAL MITTAL, ANKIT JAIN, ARTI SAXENA, VIVEK KUMAR, AND MAN MOHAN SHUKLA	
20 Real-time solar panel performance monitoring and energy forecasting	342
ANITA SHUKLA, ANKIT JAIN, PUSPRAJ SINGH CHAUHAN, AND IMRAN ULLAH KHAN	
21 Solar energy to sustainable development goals: A case study	358
KESHAV KUMAR, MAN MOHAN SHUKLA, BISHWAJEET PANDEY, AND KAMINI SIMI BAJAJ	
22 Advancements and challenges in all-perovskite tandem solar cells: A critical review	370
ANITA SHUKLA, ANKIT JAIN, PUSPRAJ SINGH CHAUHAN, AND IMRAN ULLAH KHAN	
<i>Index</i>	383

Pradeep Kumar Gupta

Department of Electronics and
Communication Engineering
Pranveer Singh Institute of
Technology Kanpur
Kanpur, India

Abhishek Jain

School of Engineering and
Technology
BML Munjal University
Gurugram, India

Ankit Jain

Department of ECE
Pranveer Singh Institute of
Technology, Kanpur
Kanpur, India

Imran Ullah Khan

Department of ECE
Integral University
Lucknow, India

Amit Kumar

Department of MCA
Gyancity Research Consultancy
Greater Noida, India

Vivek Kumar

Department of Electronics and
Communication Engineering
Pranveer Singh Institute of
Technology Kanpur
Kanpur, India

Disha Handa Mahendru

UIC, Chandigarh University
Sahibzada Ajit Singh Nagar, India

T. Mariprasath

Department of EEE
K.S.R.M College of Engineering
(Autonomous)
Kadapa, India

Anita Pati Mishra

IMS Noida
Noida, India

Preeti Agarwal Mittal

Department of Electronics and
Communication Engineering
Pranveer Singh Institute of
Technology Kanpur
Kanpur, India

Uddalak Mitra

Department of Computer Science
& Engineering
JIS College of Engineering
Kalyani, Nadia, India

Shaik Mahmmad Nazir

School of Engineering and
Technology
BML Munjal University
Gurugram, India

Priyanshu Pal

Department of Computer Science
& Engineering
JIS College of Engineering
Kalyani, Nadia, India

Pushpanjali Pandey

Department of MCA
Gyancity Research Consultancy
Greater Noida, India

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

*Anita Shukla (Department of BSH, Pranveer Singh Institute of Technology, Kanpur, shukla.anita27@gmail.com) <https://orcid.org/0000-0002-2140-4018>

Ankit Jain (Department of ECE, Pranveer Singh Institute of Technology, Kanpur, ankit2483jain@gmail.com) <https://orcid.org/0000-0002-6687-5518>

Puspraj Singh Chauhan (Department of EE, IIT, Indore, puspraj.chauhan@gmail.com) <https://orcid.org/0000-0002-9223-5733>

Imran Ullah Khan (Department of ECE, Integral University, Lucknow, iukhan@iul.ac.in) <https://orcid.org/0000-0001-5912-4911>

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

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].