

Development of Lead-free Perovskite Solar Cells: Advancements, Challenges, and Sustainable Strategies

Shanshan Gao¹, Jeong-Ju Bae², Da Seul Lee³, Tae-youl Yang², and Seong Sik Shin¹

¹Sungkyunkwan University - Suwon Campus

²Chungnam National University

³SKKU Advanced Institute of Nano Technology

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Abstract

Perovskite solar cells (PSCs) have attracted considerable attention in the field of photovoltaics owing to their high power conversion efficiency (PCE), cost-effective production methods, and versatile applications. However, the widespread use of lead (Pb)-based materials in PSCs poses challenges related to their toxicity and environmental sustainability. This review explores recent advances in the development of Pb-free perovskite materials, such as tin (Sn)-based, germanium (Ge)-based, and other B(IV) and B(III) cation alternatives, while assessing their electronic properties, stability, and performance-enhancing strategies. Additionally, we discuss the use of green solvents and fabrication techniques to minimize their environmental impact. This review aims to guide future research toward safe, efficient, and environmentally sustainable PSC technologies, ensuring that the benefits of solar energy can be harnessed without compromising human health or the environment.

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