

## REVIEW

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## Advancements in radiation resistance and reinforcement strategies of perovskite solar cells in space applications

Zhenghao Huan,<sup>ab</sup> Yifan Zheng,<sup>c</sup> Kangpeng Wang,<sup>a</sup> Zicai Shen,<sup>c</sup> Wang Ni,<sup>d</sup> Jifeng Zu<sup>a</sup> and Yuchuan Shao<sup>\*ab</sup>

Perovskite solar cells (PSCs) hold great promise for space photovoltaics (PV) due to their impressive PV performance, excellent power-to-weight ratio, and cost-effectiveness. However, the environment in space presents numerous challenges for solar cells, especially cosmic radiation. PSCs have shown remarkable resistance to various forms of radiation, such as electrons, protons, ultraviolet, and  $\gamma$ -rays. Nevertheless, their stability in space applications still lags behind that of crystalline silicon (c-Si) and gallium arsenide (GaAs) cells. To facilitate the application of PSCs in space, it is vital to enhance their long-term stability. This mini-review examines the radiation resistance of PSCs, explores the mechanisms behind radiation-induced damage, and proposes potential strategies to bolster their resistance to radiation and reinforce overall stability.

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## 1. Introduction

Metal halide perovskites (MHPs) are semiconductor materials known for their exceptional properties, allowing them to be widely utilized across various industries. These materials typically exhibit direct-transition semiconductor behavior, characterized by a high absorption coefficient and a low exciton binding energy, resulting in excellent PV performance. Furthermore, MHPs display efficient carrier transport rates, long carrier lifetimes, and significant diffusion lengths, enabling effective transfer of electrons and holes with minimal recombination.<sup>1</sup> Perovskite solar cells (PSCs) utilizing MHPs as the absorbing layer have emerged as examples of third-generation solar cells. A significant milestone in the development of PSCs was achieved in 2009 when Miyasaka *et al.* replaced the absorbing material in dye-sensitized solar cells with perovskite, resulting in a photovoltaic conversion efficiency (PCE) of 3.8%.<sup>2</sup> Since then, PSCs have garnered significant attention, and their PCE has experienced rapid growth, as depicted in Fig. 1(A).<sup>3–6</sup> Currently, single-junction PSCs have achieved a certified PCE of 26.14%,<sup>7</sup> steadily approaching the Shockley–Queisser efficiency limit of 33.7%.<sup>8</sup>

The high light absorption coefficient of MHPs allows for a significant reduction in the thickness of the absorption film to just a few hundred nanometers, providing PSCs with a high power-to-weight ratio (Fig. 1(B)). In comparison, traditional c-Si cells possess a ratio of less than 1 W g<sup>−1</sup> due to their thicker light-absorbing layer.<sup>9</sup> Triple-junction III–V semiconductor cells achieve a ratio of roughly 3 W g<sup>−1</sup> through their densely fabricated structure. In contrast, flexible single-junction PSCs can reach an impressive ratio of 23–29 W g<sup>−1</sup>, while multi-junction PSCs can surpass even that, reaching an outstanding ratio of 79–83 W g<sup>−1</sup>.<sup>10–12</sup> Based on the above comparison, the PSCs are undoubtedly better suited to meet the needs of spacecraft for lightweight energy systems. However, the long-term stability of PSCs remains the main obstacle to their pragmatic applications. Moisture can lead to hydrolysis in MHPs, while oxygen molecules can interact with photogenerated electrons in the conduction band, resulting in the formation of superoxide (O<sub>2</sub><sup>−</sup>) and accelerating the decomposition of MHPs.<sup>13</sup> If PSCs can be utilized in a space environment devoid of moisture and oxygen, these two prominent factors will be negligible, making PSCs very promising for space deployment.

While plenty of current studies on PSCs have been conducted for ground applications, there is a lack of studies focusing on their suitability in space. The space environment poses challenges due to its complexity and variability, subjecting PSCs to harsh conditions such as extreme radiation, ultra-high vacuum, and severe temperature fluctuations.<sup>14</sup> Moreover, the exorbitant cost of space flight makes it practically impossible to repair or replace PSCs once they are deployed in space. Therefore, PSCs must exhibit long-term stability and reliability to ensure the safety of spacecraft. Fortunately, research has

<sup>a</sup>Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences, 201800, Shanghai, China. E-mail: yifan.zheng@siofm.ac.cn; shaoyuchuan@siofm.ac.cn<sup>b</sup>Center of Materials Science and Optoelectronics Engineering, University of Chinese Academy of Sciences, 100049, Beijing, China<sup>c</sup>Beijing Institute of Spacecraft Environment Engineering, Beijing 100094, China<sup>d</sup>Science and Technology on Power Sources Laboratory, Tianjin Institute of Power Sources, Tianjin, 300384, China

# Reinforcement Radiation From Space Answers

**Y Pai**



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