Radiation and Environmental Stability of Metal Halide Perovskites for Space Photovoltaics

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Abstract:
Metal halide perovskites (MHPs) offer an attractive pathway to lightweight, high-efficiency solar power in space, but their resilience under orbital stressors must be rigorously validated. We present a comprehensive investigation into the optical stability and degradation modes of MHPs using ground-based irradiation experiments and in-orbit exposure across three Materials International Space Station Experiments (MISSE-13, -15, and -16).

Unencapsulated $CH_3NH_3PbI_{3-x}Cl_x$ films irradiated with 20 keV protons at fluences above 10^{13} p^+/cm^2 exhibited distinct photoluminescence (PL) quenching, bandgap blue-shifting, and shortened recombination lifetimes, indicating defect accumulation. These effects were not observed under neutron exposure alone and were partially reversible under AM1.5 light soaking, highlighting dynamic defect formation and healing mechanisms.[1] In contrast, $CH_3NH_3PbI_3$ thin films encapsulated with SiO_2 and flown on MISSE-13 for 10 months in low Earth orbit showed remarkable thermochemical and optical stability, albeit with some indications of photoinduced strain and phase stabilization. Extended light soaking post-flight significantly improved carrier lifetimes and suppressed phase transition temperatures.[2]

To bridge thin-film resilience with full device integration, we deployed complete perovskite solar cells aboard MISSE-15. While the MHP absorber layers remained emissive and structurally intact after eight months in orbit, all devices suffered electrical failure due to contact degradation and ion migration. Complementary UV filtering experiments from MISSE-16 confirmed that MAPI films retain emission and lifetime robustness even under AM0 UV exposure, though enhanced stability was observed in the least UV-exposed sample.[3]

Together, these studies establish foundational design rules for space-compatible perovskite photovoltaics, while also highlighting that optical spectroscopy can detect early radiation-induced damage before electrical failure. Further, they confirm that prolonged orbital exposure does not degrade the MHP lattice, but contact materials require re-engineering.

Conflicts of Interest
The authors declare no conflict of interest.

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