Understanding Performance and Stability of Perovskite-based Multi-Junction Solar Cells for Space Applications

Sercan Ozen[1,] Biruk Alebachew Seid[1], Etienne Beier[1], Eduardo Solano[2], Julian A. Steele[3,4], Kai O. Brinkmann[5], Thomas Riedl[5], Martin Stolterfoht[1,6], Dieter Neher[1]*

1 Institute of Physics and Astronomy, University of Potsdam, 14476 Potsdam-Golm, Germany

2 NCD-SWEET Beamline, ALBA Synchrotron Light Source, Cerdanyola del Vallès, Barcelona, 08290 Spain

3 Australian Institute for Bioengineering and Nanotechnology, The University of Queensland, Brisbane, QLD, 4072, Australia

4 School of Mathematics and Physics, The University of Queensland, Brisbane, QLD, 4072, Australia

5 Institute of Electronic Devices, University of Wuppertal, 42119 Wuppertal, Germany

6 Electronic Engineering Department, The Chinese University of Hong Kong, Hong Kong SAR, China

sercan.oezen@uni-potsdam.de

Abstract:

Multi-junction perovskite solar cells (MJ-PSCs) overcome thermalization losses and achieve high power conversion efficiencies (PCE) by combining complementary bandgaps. When fabricated on ultrathin substrates, they deliver high power-to-weight ratios that outperform conventional photovoltaic solutions for space. However, their long-term stability under the extreme conditions of space remains an open challenge. Beyond Earth's protective atmosphere, the space environment introduces unique stress factors such as atomic oxygen (AtOx), high-energy radiation, extreme thermal cycling, and low-intensity, low-temperature (LILT) environments in addition to the conventional degradation factors. In this presentation, I discuss their radiation tolerance, followed by insights into AtOx-induced degradation and MJ-PSCs operational characteristics under LILT conditions. [1–4]

Atomic oxygen (AtOx) rapidly corrodes unencapsulated perovskite solar cells (PSCs), necessitating the future use of ultralight barriers. However, micrometeorite impacts may compromise even the best encapsulation strategies. To address this risk, we investigated AtOx-induced degradation mechanisms in devices with and without phenethylammonium iodide (PEAI)-based 2D surface passivation. Surprisingly, the 2D-passivated PSCs exhibited more severe degradation. Combining injection-current-dependent electroluminescence (EL), EL imaging, intensity-dependent photoluminescence quantum yield (IPLQY) measurements, and resistance-photovoltage transients, we show that 2D passivation layers undergo accelerated degradation due to lateral diffusion of AtOx through the 2D surface, facilitated by the large interplanar spacing of the layered perovskite structure. [5]

We evaluated the performance of unpassivated all-perovskite tandem solar cells under low-intensity, low-temperature (LILT) conditions, relevant to outer planetary missions, such as those near Saturn. In this environment, characterized by irradiance levels around 0.01 AM0 and spacecraft temperatures near 100 K, the tandem devices retained only ~50% of their original power conversion efficiency (PCE). In contrast, the control single-junction (1.5 eV) perovskite cell maintained its initial performance without loss. To better understand the mechanisms behind this PCE drop, we analyzed the temperature-dependent behavior of PCE, EL, and PL in both tandem and single-junction solar cells. [8]

References

(1) Lang, F.; Eperon, G. E.; Frohna, K.; Tennyson, E. M.; Al-Ashouri, A.; Kourkafas, G.; Bundesmann, J.; Denker, A.; West, K. G.; Hirst, L. C.; Neitzert, H.-C.; Stranks, S. D. Proton-Radiation Tolerant All-Perovskite Multijunction Solar Cells. *Adv. Energy Mater.* **2021**, *11* (41), 2102246. https://doi.org/10.1002/aenm.202102246.

(2) Lang, F.; Jošt, M.; Frohna, K.; Köhnen, E.; Al-Ashouri, A.; Bowman, A. R.; Bertram, T.; Morales-

Vilches, A. B.; Koushik, D.; Tennyson, E. M.; Galkowski, K.; Landi, G.; Creatore, M.; Stannowski, B.; Kaufmann, C. A.; Bundesmann, J.; Rappich, J.; Rech, B.; Denker, A.; Albrecht, S.; Neitzert, H. C.; Nickel, N. H.; Stranks, S. D. Proton Radiation Hardness of Perovskite Tandem Photovoltaics. *Joule* **2020**, *4* (5), 1054–1069. https://doi.org/10.1016/j.joule.2020.03.006.

(3) Lang, F.; Jošt, M.; Bundesmann, J.; Denker, A.; Albrecht, S.; Landi, G.; Neitzert, H.-C. C.; Rappich, J.; Nickel, N. H. Efficient Minority Carrier Detrapping Mediating the Radiation Hardness of Triple-Cation Perovskite Solar Cells under Proton Irradiation. *Energy Environ. Sci.* **2019**, *12* (5), 1634–1647. https://doi.org/10.1039/C9EE00077A.

(4) Lang, F.; Nickel, N. H.; Bundesmann, J.; Seidel, S.; Denker, A.; Albrecht, S.; Brus, V. V.; Rappich, J.; Rech, B.; Landi, G.; Neitzert, H. C. H.-C. Radiation Hardness and Self-Healing of Perovskite Solar Cells. *Adv. Mater.* **2016**, *28* (39), 8726–8731. https://doi.org/10.1002/adma.201603326.

(5) Seid, B. A.; Sarisozen, S.; Peña-Camargo, F.; Ozen, S.; Gutierrez-Partida, E.; Solano, E.; Steele, J. A.; Stolterfoht, M.; Neher, D.; Lang, F. Understanding and Mitigating Atomic Oxygen-Induced Degradation of Perovskite Solar Cells for Near-Earth Space Applications. *Small* **2024**. https://doi.org/10.1002/smll.202311097.

(7) J. Thiesbrummel, F. Peña-Camargo, K. O. Brinkmann, E. Gutierrez-Partida, F. Yang, J. Warby, S. Albrecht, D. Neher, T. Riedl, H. J. Snaith, M. Stolterfoht, F. Lang, Understanding and Minimizing VOC Losses in All-Perovskite Tandem Photovoltaics, ARXIV, 2022.

(8) Sercan Ozen, Etienne Beier, Kai O. Brinkmann, Thomas Riedl, Martin Stolterfoht, Dieter Neher, Felix Lang All-perovskite perovskite tandems in low-temperature, low-intensity outer planetary environments, submitted