



News & Views

Recent multiple evidences for high stability of perovskite optoelectronic devices

Hongwei Han^{a,*}, Jianpu Wang^{b,*}^a Wuhan National Laboratory for Optoelectronics, Huazhong University of Science and Technology, Wuhan 430074, China^b Key Laboratory of Flexible Electronics (KLOFE) & Institute of Advanced Materials (IAM), Jiangsu National Synergetic Innovation Center for Advanced Materials (SICAM), Nanjing Tech University, Nanjing 211816, China

Organic-inorganic metal halide perovskite materials are earth-abundant and combine the advantages of both inorganic and organic materials, such as solution processing, adjustable band gap, high carrier mobility and high extinction coefficient. They are expected to break the technology bottleneck of traditional semiconductor materials and achieve the evolutionary optoelectronic devices with large-area and high efficiency at low cost [1].

The past few years have witnessed sky-rocketing increase of power conversion efficiencies (PCEs) of perovskite solar cells (PSCs) with a new certified efficiency record of 25.2%, making them a strong candidate for next generation low-cost photovoltaic technology. However, since it was first reported for solar cells in 2009 by Miyasaka group [2], the device stability is considered to be the biggest challenge hindering commercialization and has attracted much attention. Metal halide perovskite was initially used as a sensitizer in liquid dye-sensitized solar cells, which unfortunately only worked for a few seconds [2]. A breakthrough with hours of lifetime was made by using spiro-OMeTAD as the hole-conductor to fabricate a solid-state perovskite sensitized solar cells in 2012 [3,4], which opened research upsurge of perovskite solar cells. Considering the possible of material decomposition and irreversible ionic migration under multi-field conditions of light, heat or electric field, perovskite solar cells were pessimistic to realize high stability. Further progress without performance decay under continuous light-soaking for 1000 h, a standard duration in commercial PV technologies international design qualification and type approval of IEC66146 or IEC61215, was obtained by introducing bifunctional molecular, carbon electrode and triple mesoscopic structure to fabricate printable mesoscopic perovskite solar cells in 2014 by Han group [1,5–9].

Meanwhile, high stability of perovskite light-emitting diodes (LEDs) has been achieved. Due to the low PCE of traditional three-dimensional (3D) perovskite LEDs and the poor stability of perovskite films, the initial perovskite LED can only survive for less than 1 min [10]. Wang and Huang Group [11] firstly reported highly stable perovskite LED in 2016 by developing self-organized

multiple-quantum-well perovskites, which result in a high external quantum efficiency (EQE) of 11.7% and a half-lifetime of 2 h at a constant current density of 10 mA cm⁻². Through optimizing the 3D perovskite films and introducing amino-acid additives to passivate defects, they further reported perovskite LEDs with a half-lifetime of over 20 h at a high current density of 100 mA cm⁻² and a peak EQE of over 20% [12], which are comparable to the performance of near-infrared organic LEDs.

After that many groups around the world reported stable perovskite solar cells with various perovskite composition and device architecture for 1000 h durable under light-soaking. Just recently, Zhou group [13] employed fluoride to suppress the formation of both anion and cation vacancies and obtained enhancement in both the PCE and stability of the PSCs. Yang and Han group [14] once again reported a stabilized PSC within planar formal structure by constructing a Pb-rich surface and a chlorinated graphene oxide layer. Zhao group [15] reported the possibility of stabilization of all-inorganic perovskite-perovskite solar cells.

How to restrain the decomposition of perovskite materials is the primary scientific problem to achieve stable devices. To solve the problem, Zhou group [13] introduces the extremely high electronegative fluoride into perovskite layer to achieve the dual passivation effect by forming strong hydrogen bond with organic cations and strong ionic bond with lead ions. This effectively eliminates the vacancy defects of organic cations and halogen anions in perovskites. As a result, the PCE and long-term stability of corresponding devices are greatly improved. In addition, Wang and Huang Group demonstrate water-stable PSCs through the design of hydrophobic quasi-2D layered perovskites [16]. By introducing 3-bromobenzylammonium iodide to form energetically ordered and highly crystalline perovskite films, the unencapsulated PSCs can maintain over 82% of the initial efficiency after 2400 h under relative humidity of 40%. From another view, the heterostructure of perovskites with other semiconductors, where the photogenerated charge carriers are separated and transported to external circuit, is the essential structure of PSCs for efficient conversion of light into electricity. It has been reported that the product of the decomposition of perovskite will destroy the charge transport layer, which indicates the disintegration of the heterojunction structure, resulting in a decrease in device stability. Yang and

* Corresponding authors.

E-mail addresses: hongwei.han@mail.hust.edu.cn (H. Han), iamjpwang@njtech.edu.cn (J. Wang).

Han group [14] constructed a stabilized heterostructure. The Pb-rich surface was obtained by spin-coating lead thiocyanate or lead acetate solution on perovskite surface at low temperature. Extra lead will be left after the heat treatment. Subsequently, chlorine-doped graphene oxide was coated on this surface. Chlorine can bond with lead and increase the binding force of oxygen, helping oxygen form stronger bonding with lead. Accordingly, the Pb-rich surface firmly combined with chlorine-doped graphene oxide to form a heterostructure. The compact chlorine-doped graphene oxide layer can prevent the decomposition products from reacting with the charge transport layer. Moreover, due to the optimized alignment of energy levels, the overall energy loss can be reduced with less charge recombination. The fabricated PSCs achieved an initial efficiency of 21% with an aperture area of 1.02 cm [2]. At the maximum power point, the device maintained 90% of the initial efficiency after 1000 h of continuous operation at 60 °C under AM 1.5G illumination.

Progress has been made in all-inorganic PSCs as well. Though all-inorganic PSCs using $\text{CsPbI}_x\text{Br}_{1-x}$ as light-absorbers have advantages in stability, the PCEs are lower than those of the hybrid organic-inorganic metal halide PSCs due to the large bandgap. Zhao group [15] for the first time demonstrated an ambient condition stable β -phase CsPbI_3 with a more favorable bandgap and increased the record PCE of all-inorganic PSC to 18.4%.

These works provide multiple evidences for the high stability of perovskite optoelectronics devices and are an important step toward their future application. Further understanding of the mechanism of perovskite material decomposition and device stability under multi-field conditions and how the device inhibits ion migration will help to develop more efficient and stable devices.

Conflict of interest

The authors declare that they have no conflict of interest.

References

- [1] Rong YG, Hu Y, Mei A, et al. Challenges for commercializing perovskite solar cells. *Science* 2018;361:eaat8235.
- [2] Kojima A, Teshima K, Shirai Y, et al. Organometal halide perovskites as visible-light sensitizers for photovoltaic cells. *J Am Chem Soc* 2009;131:6050–1.
- [3] Kim H-S, Lee C-R, Im J-H, et al. Lead iodide perovskite sensitized all-solid-state submicron thin film mesoscopic solar cell with efficiency exceeding 9%. *Sci Rep* 2012;2:591.
- [4] Lee MM, Teuscher J, Miyasaka T, et al. Efficient hybrid solar cells based on meso-structured organometal halide perovskites. *Science* 2012;338:643–7.
- [5] Mei A, Li X, Liu L, et al. A hole-conductor-free, fully printable mesoscopic perovskite solar cell with high stability. *Science* 2014;345:295–8.
- [6] Hu Y, Zhang Z, Mei A, et al. Improved Performance of printable perovskite solar cells with bifunctional conjugated organic molecule. *Adv Mater* 2018;30:1705786.
- [7] Ku ZL, Rong YG, Xu M, et al. Full printable processed mesoscopic $\text{CH}_3\text{NH}_3\text{PbI}_3/\text{TiO}_2$ heterojunction solar cells with carbon counter electrode. *Sci Rep* 2013;3:3132.
- [8] Liu L, Mei A, Liu T, et al. Fully printable mesoscopic perovskite solar cells with organic silane self-assembled monolayer. *J Am Chem Soc* 2015;137:1790–3.
- [9] Rong Y, Liu L, Mei A, et al. Beyond efficiency: the challenge of stability in mesoscopic perovskite solar cells. *Adv Energy Mater* 2015;5:1501066.
- [10] Tan ZK, Moghaddam RS, Lai ML, et al. Bright light-emitting diodes based on organometal halide perovskite. *Nat Nanotechnol* 2014;9:687–92.
- [11] Wang N, Cheng L, Ge R, et al. Perovskite light-emitting diodes based on solution-processed self-organized multiple quantum wells. *Nat Photonics* 2016;10:699.
- [12] Cao Y, Wang N, Tian H, et al. Perovskite light-emitting diodes based on spontaneously formed submicrometre-scale structures. *Nature* 2018;562:249.
- [13] Li NX, Tao S, Chen Y, et al. Cation and anion immobilization through chemical bonding enhancement with fluorides for stable halide perovskite solar cells. *Nat Energy* 2019;4:408–15.
- [14] Wang Y, Wu T, Barbaud J, et al. Stabilizing heterostructures of soft perovskite semiconductors. *Science* 2019;365:687.
- [15] Wang Y, Dar MI, Ono LK, et al. Thermodynamically stabilized beta-CSPbI₃-based perovskite solar cells with efficiencies >18%. *Science* 2019;365:591.
- [16] Yang R, Li R, Cao Y, et al. Oriented quasi-2D perovskites for high performance optoelectronic devices. *Adv Mater* 2018;30:1804771.



Hongwei Han is Professor at Wuhan National Laboratory for Optoelectronics (WNLO), Huazhong University of Science and Technology (HUST) in China. He received his B.S. degree in Applied Chemistry and his Ph.D. degree in Condensed Matter Physics from Wuhan University in 2000 and 2005, respectively. And then he worked as postdoctoral research fellow at Monash University in Australia. He joined HUST and WNLO in 2008. Since 2000, he has worked on the printable mesoscopic photovoltaic and optoelectronic devices.



Jianpu Wang has been a Professor at Nanjing Tech University since 2013. Prior to NanjingTech, he was a postdoctoral research associate studying organic magnetic field effect in Cavendish Laboratory, University of Cambridge in 2009–2013. And he did his Ph.D. study also in Cavendish from 2006 to 2009, when he investigated organic semiconductor/inorganic nanocrystal devices. He worked as a research engineer in Samsung Electronics in South Korea in 2003–2006, for developing OLED displays by using ink-jet printing technology. His research interests are organic/perovskite semiconductor devices and device physics, aiming for display and energy applications.