Science Bulletin 67 (2022) 2263–2264

Contents lists available at ScienceDirect

Science Bulletin

journal homepage: www.elsevier.com/locate/scib

Research Highlight

Efficient perovskite solar cells with body temperature self-repairing

Rongrong Bao [a,b], Caofeng Pan [a,b,*]

[a] CAS Center for Excellence in Nanoscience, Beijing Key Laboratory of Micro-nano Energy and Sensor, Beijing Institute of Nanoenergy and Nanosystems, Chinese Academy of Sciences, Beijing 100083, China

[b] School of Nanoscience and Technology, University of Chinese Academy of Sciences, Beijing 100049, China

In recent years, the development of wearable devices has a growing demand for flexible solar cells. Among them, improving the efficiency of the cells, enhancing the stability of device performance during bending and achieving self-repairing are important focuses of researchers. Perovskite materials have been found to be one of the new materials to improve the efficiency of flexible solar cells [1,2]. At present, the problem to be solved is the degradation of device performance during bending, which due to defects of perovskite films on flexible substrate and grain boundaries cracks-triggered increased series resistance and carrier leakage [3,4]. Some researcher reported the self-repairing of flexible perovskite solar cells (PSCs) by introduction of self-healing polymers [5]. For example, the flexible PSCs using self-healing polyurethane (s-PU) as a scaffold in the perovskite crystallization process can recover more than 90% of the initial PCE, after 1000 times of 20% tensile cycles [6]. However, these self-repairing processes usually require high temperature to achieve, which is very inconvenient for the application as wearable devices. Recently, Song's group [7] from the Institute of Chemistry, Chinese Academy of Sciences reported a new type of self-repairing PSC based on shape memory scaffold polyurethane (SMPU). Adding the SMPU brings three advantages to PSC: (1) the device efficiency is as high as 21.33%; (2) slow down the performance degradation during deformation; (3) the device can real-time self-repair at human body temperature. These advantages provide great convenience and possibility for the application of PSC in wearable field.

Fig. 1a shows the two-step process for the preparation of PSC film, including the first step of forming three-dimensional porous scaffold from the PbI_2 solution containing SMPU, and the second step of reacting with the organic amine cation solution to form perovskite films. The morphology of the perovskite film with SMPU was studied by scanning electron microscope (SEM) images (Fig. 1b). It can be seen that the perovskite crystals grew in the vertical micro-parallel direction and the crystal quality improved compared with the film without SMPU. The preparation process and crystallization process of the thin film were studied by SEM and atomic force microscope (AFM). The optimal addition of SMPU was 0.02%. The molecular structure of the SMPU additive is shown in Fig. 1c. A n-i-p planar PSC with a PEN/ITO/SnO_2/Perovskite/Spiro-OMeTAD/Au configuration has been fabricated to study the effect of SMPU additives on device performance. The cross-sectional SEM image of device is shown in Fig. 1d. From the summary of the power conversion efficiency (PCE) distribution of 60 PSCs with and without SMPU manufactured in 6 batches, which is shown in Fig. 1e, Song's group can find that the maximum PCE of the device increases from about 19% to exceeding 21% after adding SMPU. It is due to SMPU uniformly located at grain boundary of the perovskite films to form a cross-linked network, which enhances grain size, passivates grain boundaries defect, and greatly releases mechanical stress.

Furthermore, the efficiency during bending and self-repairing performance of the flexible PSC with SMPU were studied and compared with the control perovskite film. When the same horizontal displacement is added (0.61–3 μm), the crack of the perovskite film with SMPU is smaller and much more uniform, which is due to the filamentous connection of SMPU in the crack, making the stress distribution more uniform (Fig. 1f). After being heated at 37 °C for 30 min, the broken perovskite film can be self-repaired by the SMPU (Fig. 1f–h). However, the perovskite film without SMPU has no change before and after heat treatment (37 °C, 30 min). The self-repair ability of SMPU material is due to the low temperature melting brought by the soft segments melting of this polymer material [7]. PSC with SMPU is almost completely attenuated after 10,000 bending cycles with a bending radius 8 mm, and can recover more than 80% of the original PCE after 6000 cycles, while the performance of the control devices is almost completely destroyed after 2500 bending cycles. Therefore, the addition of SMPU improves the flexibility and stability of PSC in many aspects.

In summary, a new type of PSC containing human body temperature self-repairing SMPU was designed, prepared, and studied. Since the addition of SMPU is beneficial to the uniform crystallization of perovskite and the release of stress in the film, the PSC has an ultra-high efficiency of up to 21.33%, and has the ability to slow down the damage and reduce the resistance during bending. Even after bending damage (6000 cycles under an 8 mm bending radius), it can recover 80% original PCE under human body temperature. This study provides the possibility to solve the bottleneck problem of PSC application in wearable devices.

* Corresponding author.
E-mail address: cfpan@binn.cas.cn (C. Pan).

https://doi.org/10.1016/j.scib.2022.11.003

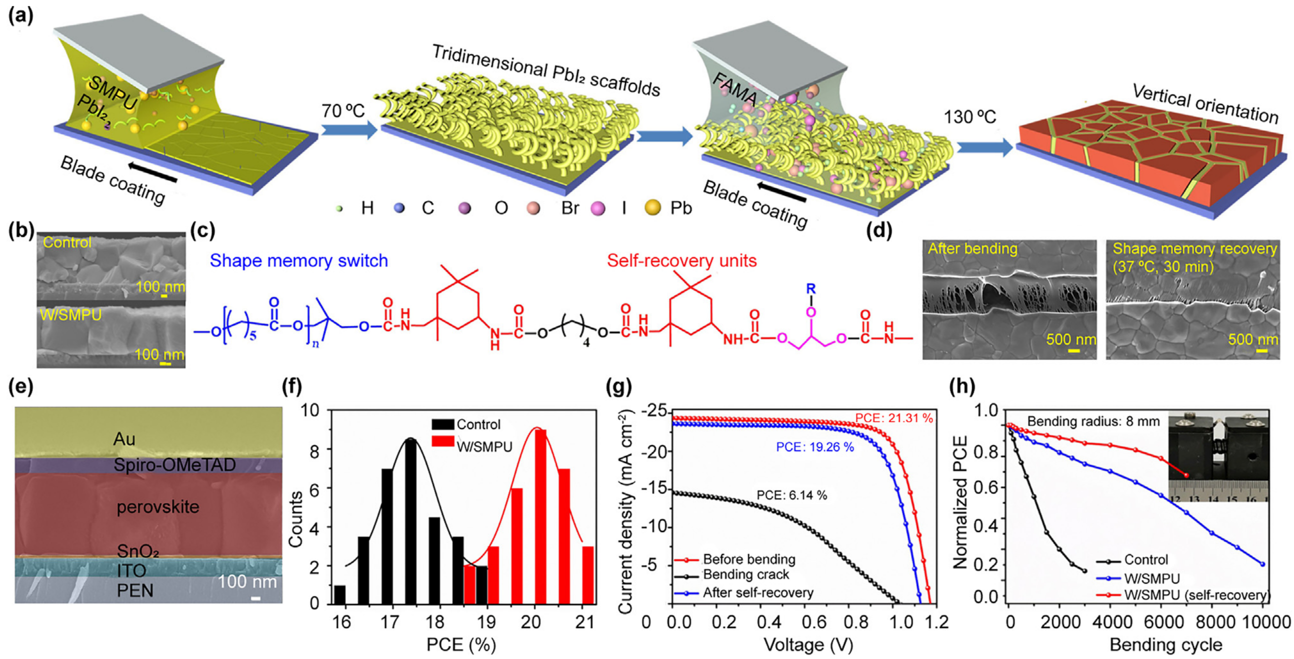


Fig. 1. Efficient perovskite solar cells with body temperature self-repairing [7]. (a) Schematic diagram of two step preparation of PSC films with SMPU, including preparation of porous PbI2 films and reaction with organic amine. (b) Cross sectional SEM images of perovskite crystalline films with and without SMPU. (c) The molecular structure of the SMPU additive. (d) Cross-sectional SEM image of the PSCs with SMPU. (e) Histograms of the PCE distribution for 60 PSCs with and without SMPU. (f) Cross-sectional SEM image of self-repairing process of SMPU at the grain boundaries of perovskite films. (g) Bending recovery performance of the devices with SMPU. (h) Normalized average PCE of PSCs as a function of bending cycles with bending radius of 8 mm.

Conflict of interest

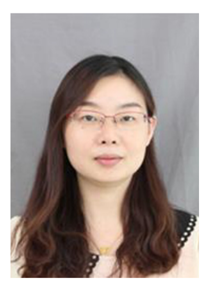
The authors declare that they have no conflict of interest.

Acknowledgments

This work was supported by the Natural Science Foundation of Beijing Municipality (2222088, L223006, and Z180011), the National Key R&D Program of China (2021YFB3200302 and 2021YFB3200304), the National Natural Science Foundation of China (52125205, U20A20166 and 52192614), Shenzhen Science and Technology Program (KQTD20170810105439418), and the Fundamental Research Funds for the Central Universities.

References

[1] Gong Y, Zhang YZ, Fang S, et al. Artificial intelligent optoelectronic skin with anisotropic electrical and optical responses for multi-dimensional sensing. Appl Phys Rev 2022;9:021403.
[2] Su M, Song Y. Printable smart materials and devices: strategies and applications. Chem Rev 2022;122:5144–64.
[3] Li D, Lai WY, Zhang YZ, et al. Printable transparent conductive films for flexible electronics. Adv Mater 2018;30:1704738.
[4] Meng X, Cai Z, Zhang Y, et al. Bio-inspired vertebral design for scalable and flexible perovskite solar cells. Nat Commun 2020;11:3016.
[5] Zhang Q, Duan J, Guo Q, et al. Thermal-triggered dynamic disulfide bond self-heals inorganic perovskite solar cells. Angew Chem Int Ed 2022;61:e2021166.
[6] Meng X, Xing Z, Hu X, et al. Stretchable perovskite solar cells with recoverable performance. Angew Chem Int Ed 2020;59:16602–8.
[7] Xue TY, Huang ZQ, Zhang P, et al. A shape memory scaffold for body temperature self-repairing wearable perovskite solar cells with efficiency exceeding 21%. InfoMat 2022;3:e12358.



Rongrong Bao received her B.S. degree from Tianjin University in 2007 and Ph.D. degree from Technical Institute of Physics and Chemistry, Chinese Academy of Sciences (CAS) in 2012. She had been a postdoc fellow in the same institute. She has been an associate professor in the group of Prof. Caofeng Pan at Beijing Institute of Nanoenergy and Nanosystems, CAS since 2016. Her main research interest focuses on the fields of the production and characterization of organic–inorganic composite nano-devices and flexible pressure sensor.

Caofeng Pan received his B.S. (2005) and Ph.D. (2010) degrees in Materials Science and Engineering from Tsinghua University. Then he joined the group of Prof. Zhong Lin Wang at the Georgia Institute of Technology as a postdoctoral fellow. He has been a professor and a group leader at Beijing Institute of Nanoenergy and Nanosystems, CAS since 2013. His research interest mainly focuses on the photoelectric nano-device, flexible electronics, sensors, and intelligent sensing systems.