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HIGHLIGHT

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Efficient and stable perovskite–silicon two-terminal tandem solar cells

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In the past several years, perovskite solar cells (PSCs) exhibited unexpected breakthrough and rapid evolution, and the power conversion efficiency (PCE) of single-junction PSCs has been increased significantly from 3.81 to 25.2% [1, 2], resulting from materials engineering, interface engineering, crystallization engineering, fabrication engineering, etc. [3–5]. In the case of silicon solar cells, the record PCE is up to 26.7%, and it is very close to the theoretical Shockley–Queisser limit [2, 6]. In order to overcome the efficiency limitation of single-junction devices and reduce the cost, perovskite–silicon tandem route can be potentially used to construct more efficient solar cells via stacking complementary wide-band gap perovskite absorber and narrow-band gap silicon absorber [7]. Traditional crystalline silicon solar cells can absorb visible light and near-infrared light over the solar spectrum and convert them into electrical energy, but photons in the visible region have thermal relaxation phenomena that cause a portion of the energy to be lost in the form of thermal energy. Using tandem solar cell technology, a polycrystalline perovskite film device that can efficiently convert visible light is directly prepared on the surface of a crystalline silicon solar cell, while a silicon solar cell is only responsible for converting infrared light transmitted through the perovskite film, which would greatly enhance the PCEs over 30%. Recently, two papers published in *Science* reported efficient and stable perovskite–silicon two-terminal tandem solar cells [8, 9].

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Xu et al. [8] studied perovskite–silicon two-terminal tandem solar cells and demonstrated that the PCE of ~ 21% silicon solar cells could be enhanced to 27%, about 30% enhancement, in 1-cm^2 tandem solar cells (Fig. 1a–c). The top perovskite solar cell with a wide-band gap of 1.67 eV was tailored using triple-halide alloys (chlorine, bromine, iodine). It is meaningful that they directly incorporated Cl into the lattice at much larger amounts than previously reported and observed a uniform halide distribution throughout the material with a reduction in lattice parameter and an increase in band gap corresponding to increasing the amounts of Cl in the lattice, leading to the increases in photocarrier lifetime and mobility and the suppression of light-induced phase segregation even at 100-sun illumination intensity. More importantly, the semitransparent top perovskite solar cell was very stable and only exhibited less than 4% degradation after 1000-h maximum power point (MPP) operation at 60 °C. As shown in Fig. 1c, in a *J–V* sweep, a typical tandem solar cell reached a PCE of 27.13% (V_{oc} = 1.886 V, J_{sc} = 19.12 mA·cm^{-2}, and FF = 75.3%) and the stabilized PCE at MPP is 27.04%.

Meanwhile, Hou et al. [9] reported perovskite–silicon two-terminal tandem solar cells that combined solution-processed micrometer-thick, wide-band gap perovskite top cell (1.68 eV gap) with fully textured silicon heterojunction bottom solar cell (Fig. 1e). A threefold enhanced depletion width in the perovskite semiconductor at the valleys of silicon pyramids was achieved, resulting in the improvement in the carrier collection. A concentrated precursor was used to produce high-quality micrometer-thick perovskite with large grain sizes and fully covering the micrometer-sized pyramids. The bulk properties of the perovskite film could be stabilized via a self-limiting

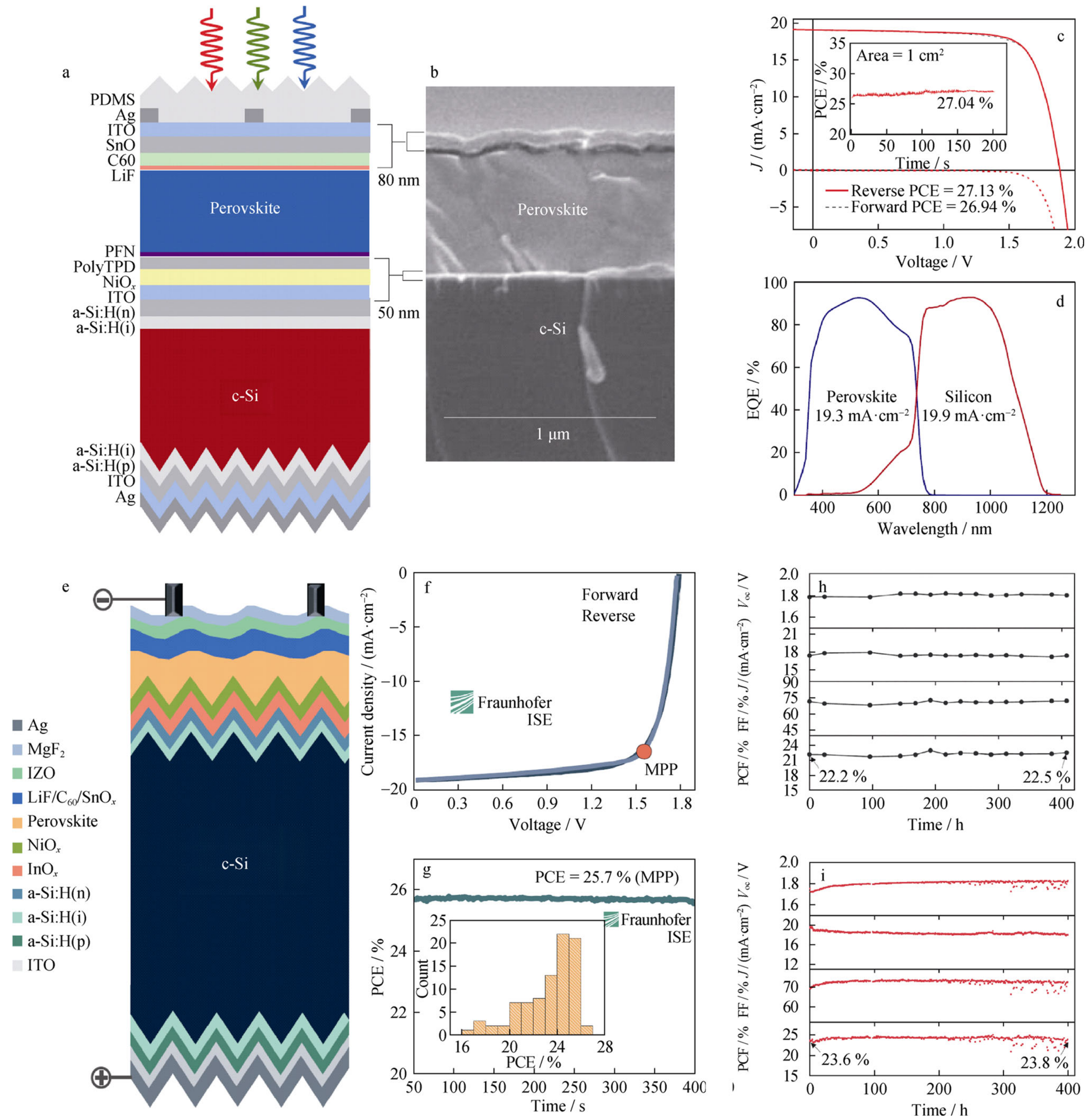

Fig. 1 Photovoltaic characteristics of 1-cm^2 two-terminal perovskite–silicon tandems [8]: **a** schematic of two-terminal tandem structure, **b** cross-sectional SEM image of a two-terminal tandem, **c** light and dark *J*–*V* curves and MPP tracking (inset) of champion tandem, and **d** external quantum efficiency (EQE) spectra of perovskite top cell (blue) and silicon bottom cell (red) of champion tandem. Photovoltaic characteristics and stability of 0.83-cm^2 two-terminal perovskite–silicon tandems [9]: **e** schematic of solution-processed perovskite-textured silicon tandem architecture, **f** *J*–*V* characteristics of certified SLP-treated textured tandems, **g** MPP tracking of certified SLP-treated textured tandems and PCE distributions of 88 individual tandem devices, **h** *J*–*V* parameters measured over a 400-h stability test at 85 °C (relative humidity ～ 45%–50%), and **i** *J*–*V* parameters measured over 400 h of light-soaking under MPP load at 40 °C. Copyright © 2020 American Association for the Advancement of Science

passivation (SLP) treatment using 1-butanethiol vapor, leading to the enhanced diffusion length and the suppressed phase segregation. Thus, an independently certified PCE of 25.7% (V_{oc} = 1.781 V, J_{sc} = 19.07 mA·cm^{-2}, and FF = 75.4%) was achieved for 0.83-cm^2 tandem solar cell (Fig. 1f, g). Furthermore, these encapsulated perovskite–silicon tandem solar cells were very stable and exhibited negligible performance loss after a 400-h thermal stability test at 85 °C in the dark at ~ 40% relative humidity and also after 400 h under MPP tracking at 40 °C and ~ 40%–50% relative humidity (Fig. 1h, i).

These two works separately demonstrated highly efficient and stable perovskite–silicon two-terminal tandem solar cell technologies. The single-junction silicon solar modules currently account for over 90% of the global photovoltaic market with the PCEs of 19%–21%. Thus, these perovskite–silicon two-terminal tandem solar cell technologies have greatly potential applications because of their higher efficiency and low cost. The wide-band gap perovskite semitransparent top solar cells offer a promising path to produce perovskite–silicon tandem solar cells with the PCEs over 30%. Although the top perovskite semitransparent top solar cells or perovskite–silicon tandem solar cells exhibited good stability over 1000 h or 400 h in these two studies, it is still much less than commercial silicon solar cells with the stability time over 25 years. It is necessary to do more work to further enhance the stability of top perovskite semitransparent top solar cells and perovskite–silicon tandem solar cells. On the other hand, large-area efficient perovskite–silicon tandem solar cells (much bigger than 1 cm^2) and modules are necessary to be further developed for accelerating their potential commercialization from the labs.

References

[1] Kojima A, Teshima K, Shirai Y, Miyasaka T. Organometal halide perovskites as visible-light sensitizers for photovoltaic cells. J Am Chem Soc. 2009;131(17):6050.

[2] www.nrel.gov/pv/assets/images/efficiency-chart.png.

[3] Bai Y, Meng XY, Yang SH. Interface engineering for highly efficient and stable planar p-i-n perovskite solar cells. Adv Energy Mater. 2018;8(5):1701883.

[4] Seok SI, Grätzel M, Park NG. Methodologies toward highly efficient perovskite solar cells. Small. 2018;14(20):1704177.

[5] Luo DY, Su R, Zhang W, Gong QH, Zhu R. Minimizing non-radiative recombination losses in perovskite solar cells. Nat Rev Mater. 2020;5(1):44.

[6] Shockley W, Queisser HJ. Detailed balance limit of efficiency of p-n junction solar cells. J Appl Phys. 1961;32(3):510.

[7] Leijtens T, Bush KA, Prasanna R, McGehee MD. Opportunities and challenges for tandem solar cells using metal halide perovskite semiconductors. Nat Energy. 2018;3(10):828.

[8] Xu JX, Boyd CC, Yu ZSJ, Palmstrom AF, Witter DJ, Larson BW, France RM, Werner J, Harvey SP, Wolf EJ, Weigand W, Manzoor S, van Hest MFAM, Berry JJ, Luther JM, Holman ZC, McGehee MD. Triple-halide wide-band gap perovskites with suppressed phase segregation for efficient tandems. Science. 2020;367(6482):1097.

[9] Hou Y, Aydin E, De Bastiani M, Xiao CX, Isikgor FH, Xue DJ, Chen B, Chen H, Bahrami B, Chowdhury AH, Johnston A, Baek SW, Huang ZR, Wei MY, Dong YT, Troughton J, Jalmood R, Mirabelli AJ, Allen TG, Van Kerschaver E, Saidaminov MI, Baran D, Qiao QQ, Zhu K, De Wolf S, Sargent EH. Efficient tandem solar cells with solution-processed perovskite on textured crystalline silicon. Science. 2020;367(6482):1135.