

Low-Bandgap Organic Bulk-Heterojunction Enabled Efficient and Flexible Perovskite Solar Cells

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Lead halide perovskite and organic solar cells (PSCs and OSCs) are considered as the prime candidates currently for clean energy applications due to their solution and low-temperature processability. Nevertheless, the substantial photon loss in near-infrared (NIR) region and relatively large photovoltage deficit need to be improved to enable their uses in high-performance solar cells. To mitigate these disadvantages, low-bandgap organic bulk-heterojunction (BHJ) layer into inverted PSCs to construct facile hybrid solar cells (HSCs) is integrated. By optimizing the BHJ components, an excellent power conversion efficiency (PCE) of 23.80%, with a decent open-circuit voltage (V_{oc}) of 1.146 V and extended photoresponse over 950 nm for rigid HSCs is achieved. The resultant devices also exhibit superior long-term (over 1000 h) ambient- and photostability compared to those from single-component PSCs and OSCs. More importantly, a champion PCE of 21.73% and excellent mechanical durability can also be achieved in flexible HSCs, which is the highest efficiency reported for flexible solar cells to date. Taking advantage of these impressive device performances, flexible HSCs into a power source for wearable sensors to demonstrate real-time temperature monitoring are successfully integrated.

1. Introduction

Metal halide perovskite solar cells (PSCs), with impressive efficiencies driven by their high absorption coefficients and long-range balanced carrier transport lengths, have attracted enormous attention as an emerging photovoltaic (PV) technology in the past decade.^[1–7] The record power conversion

efficiency (PCE) of PSCs has skyrocketed from 3.8% to 25.5% within a decade, which is unprecedented among PV technologies in such a short period of time.^[8–10] Particularly, their low-temperature solution processability and relatively good mechanical durability compatible with flexible or stretchable applications are advantageous compared with crystalline silicon (c-Si) based solar cells that are rigid and grown under high temperatures.^[11–13]

However, the record efficiency of PSCs is limited by their near infrared (NIR) photon loss from solar spectrum due to nonideal absorption onset below 850 nm for Pb-based perovskites. One way to overcome NIR photon loss is to tailor the bandgap (E_g) by adjusting perovskite compositions.^[14–17] The seminal studies performed to partially substitute Pb with Sn have successfully extended the absorption to over 1000 nm (with E_g of ≈ 1.25 eV). Nonetheless, the large open-circuit voltage (V_{oc}) deficit (≈ 0.4 V) and easy oxidation of

Sn^{2+} to Sn^{4+} upon exposure to trace amounts of oxygen have seriously hindered their further development for practical applications.^[18–20] In addition to altering compositions, engineer the device configurations is another way to extend photoresponse. For example, perovskite based tandem solar cells (TSCs) composed of two subcells having complementary absorption have been reported to be able to harvest NIR photons and suppress

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thermalization loss efficiently.^[21–23] However, the fabrication of tandem cells is quite tedious and troublesome, requiring proper composition and thickness of active layers for achieving matched photocurrents, suitable band alignment for effective charge carrier transport, delicate design and optimization of subcell configuration and interconnecting layer (ICL) for reducing energy loss, and careful optical structure design to mitigate the parasitic absorption, which significantly impede their widespread implementation.

Fortunately, the rapid progress made in organic solar cells (OSCs) as a result of the vigorous development of non-fullerene acceptors (NFAs) represented by the low-bandgap 2,2'-((2Z,2''Z)-((12,13-bis(2-ethylhexyl)-3,9-diundecyl-12,13-dihydro-[1,2,5]thiadiazolo[3,4-e]thieno[2'',3''':4',5'']thieno[2'',3'':4,5]pyrrolo[3,2-g]thieno[2'',3'':4,5]thieno[3,2-b]indole-2,10-diyl)bis(methanylylidene))bis(5,6-difluoro-3-oxo-2,3-dihydro-1H-indene-2,1-diylidene))di-malononitrile (Y6), has enabled the fabrication of novel hybrid solar cells (HSCs) with PSC.^[24–26] The short-circuit current densities (J_{sc}) could be increased due to the complementary absorption of bulk-heterojunction (BHJ) OSC and PSC without sacrificing the photovoltages.^[27–31] The combined low-temperature solution processibility, simplified device structures, and high PCEs will enable these hybrid devices to be used for high-efficiency flexible solar cells with lowered manufacturing cost.

To realize these merits, we have fabricated an inverted HSC with extended photoresponse over 950 nm by using a ternary blend of poly[(2,6-(4,8-bis(5-(2-ethylhexyl-3-fluoro)thiophen-2-yl)-benzo[1,2-b:4,5-b']dithiophene))-alt-(5,5-(1',3'-di-2-thienyl-5',7'-bis(2-ethylhexyl) benzo[1',2'-c:4',5'-c']dithiophene-4,8-dione)] (PM6): 2,10-bis (2-methylene-(3-(1,1-dicyano- methylene)-5,6-difluorindanone))-12,13-bis(2-butyl-octyl)-3,9-diundecyl diselenopheno [2'',3'':4',5'']thieno [2'',3'':4,5]pyrrolo[3,2-e:2',3'-g][2,1,3] benzothiadiazole (CH1007): phenyl-C61-butyric acid methyl ester (PCBM) as the organic BHJ. CH1007 NFA, with ≈ 60 nm redshifted absorption than Y6, is selected as an efficient harvester for NIR photons, while PCBM with excellent carrier mobility is incorporated to enhance electron transport. More importantly, the presence of a small quantity of PM6 donor polymer facilitates the exciton dissociation in organic BHJ and improves its device stability. With these synergistic attributes, we have successfully achieved a champion PCE of 23.80% in an inverted HSC with superior long-term device stability. Taking advantage of the low temperature processibility, flexible HSCs are also fabricated to show not only good mechanical flexibility but also a PCE as high as 21.73%, which is utilized to power a wearable temperature sensor for real-time monitoring.

2. Results and Discussion

The molecular structures of donor polymer PM6, low-bandgap NFA CH1007, and PCBM used in this study are shown in **Figure 1a** and their corresponding ultraviolet–visible (UV–vis) absorption spectra are provided in **Figure 1b**. The absorption onset of perovskite used in this study is ≈ 800 nm, corresponding to a E_g of 1.55 eV (calculated from the Tauc plot, **Figure S1**, Supporting Information), while the low-bandgap acceptor CH1007 exhibits strong absorption bands between 650

and 1000 nm. Therefore, the NIR photon loss in PSC can be reduced by integrating a CH1007 containing BHJ layer with a perovskite layer to capture the low-energy photons, as shown in **Figure S2** (Supporting Information).

To understand the charge transfer dynamics between perovskite and different organic blends, we conducted both steady-state and time-resolved photoluminescence (PL and TRPL) spectroscopies for the perovskite films coated with PCBM, CH1007: PCBM, or PM6: CH1007: PCBM layer, which were sequentially deposited on quartz substrates. As shown in **Figure 1c**, the PL emission from perovskite with a peak at 800 nm were significantly quenched upon contacting with organic blends, indicating efficient charge transfer from perovskite to organic layers.^[28,29] Surprisingly, a relatively weak PL peak was observed at around 950 nm for both perovskite/CH1007: PCBM and perovskite/PM6: CH1007: PCBM, which might be assigned to the emission from photoexcited CH1007.^[31] The higher PL intensity from CH1007 for perovskite/CH1007: PCBM can be attributed to the insufficient driving force for exciton dissociation in the absence of D–A interfaces.

As for TRPL, all the samples were excited at 480 nm and detected at 800 nm which is the PL peak of perovskite. The bare perovskite film exhibited a long PL lifetime of 832.43 ns due to the efficient radiative recombination from photogenerated carriers, while it was remarkably reduced to 19.67, 21.85, and 2772 ns for the perovskite films contacted with PCBM, CH1007: PCBM, and PM6: CH1007: PCBM, respectively (as shown in **Figure 1d**, and summarized in **Table S1**, Supporting Information). We note that both CH1007: PCBM and PM6: CH1007: PCBM exhibited comparable PL quenching for perovskite and similar PL lifetime as that with PCBM, indicating fast charge extraction. The slightly longer PL lifetime observed for perovskite/CH1007: PCBM and perovskite/PM6: CH1007: PCBM might be originated from the defect passivation by the electron-rich functional groups on donor and acceptor on perovskite, which have been widely reported in previous studies.^[32–34] These results confirm efficient charge extraction occurred at the interface between perovskite and organic BHJ, and the proposed carrier transport path is depicted in **Figure 1e**.

Prior to device fabrication, the device level electromagnetic-field (E-field) intensity distribution was simulated to assess the photon utilization across perovskite and organic photoactive layers, as portrayed in **Figure 1f–h**; and **Figure S3** (Supporting Information). Given the thick perovskite layer and its optical bandgap of 1.55 eV, the photons with wavelength (λ) < 800 nm are mainly concentrated in perovskite layer. By contrast, the photons with λ of 800–950 nm are efficiently absorbed by CH1007: PCBM and PM6: CH1007: PCBM layer, ensuring the maximum photocurrent generation in the device. Additionally, the lowest unoccupied molecular orbital (LUMO) for CH1007 (3.91 eV) is well-aligned with the conduction band minimum (CBM) of perovskite, suggesting efficient electron transport from perovskite to CH1007 can be achieved, as shown in **Figure 2a**; and **Figures S4** and **S5** (Supporting Information).^[35]

To explore whether CH1007 layer can act as both efficient electron-transporting layer (ETL) and generation of photocurrent, the inverted PSCs based on CH1007 and PCBM ETL were fabricated with the device structure of indium tin oxide (ITO)/poly (triaryl amine) (PTAA)/perovskite/CH1007 or

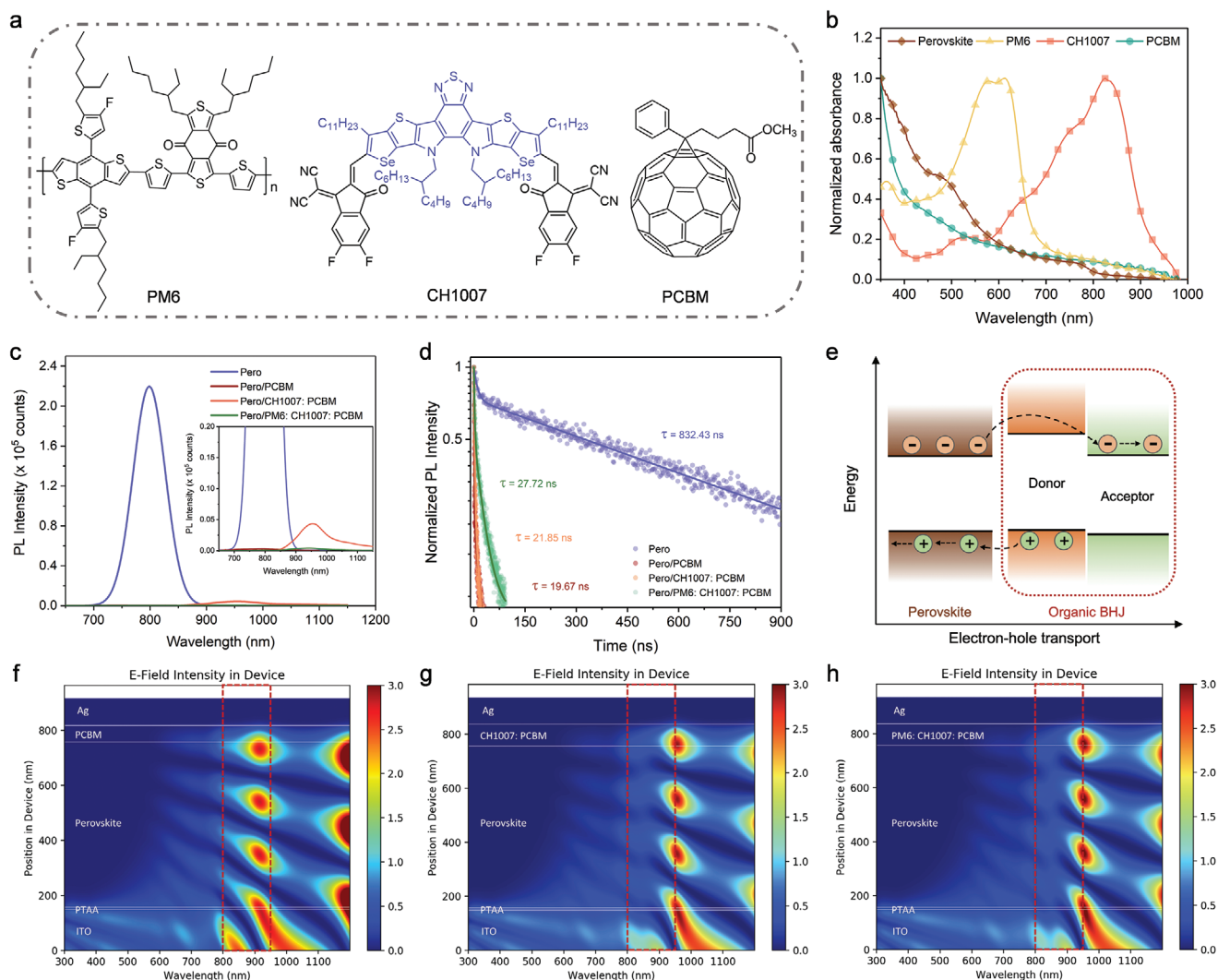


Figure 1. a) The molecular structures of PM6, CH1007, and PCBM. b) UV-vis absorbance spectra of perovskite, PM6, CH1007, and PCBM thin films. c) Photoluminescence spectra (PL) and d) time-resolved photoluminescence spectra (TRPL) of perovskite films spin-coated on quartz and coated with PCBM, CH1007: PCBM, and PM6: CH1007: PCBM, respectively. e) Schematics depicting carrier transport path between perovskite and organic bulk heterojunction (BHJ). f–h) Simulated electromagnetic-field distribution within a complete solar cell based on different organic layer and blends on top of perovskite layer.

PCBM/bathocuproine (BCP)/Ag. Moreover, the surface passivation strategies reported in our previous studies for perovskite layer were also employed to suppress the energy loss from bulk- and interface-induced nonradiative recombination (Figure S6, Supporting Information).^[36,37] As plotted in Figure S7 (Supporting Information), the device with CH1007 layer had a lower fill factor (FF) of 72.71%, resulting in a PCE of 20.09%. In comparison, the control PSC based on PCBM ETL obtained a PCE of 22.44% owing to its significantly higher FF of 82.19% (Figures S7 and S8, Supporting Information). The electron mobilities (μ_e) of CH1007 and PCBM were calculated based on the space-charge-limited-current (SCLC) measurement, as illustrated in Figure S9 (Supporting Information).^[38] The results clearly showed that the μ_e of CH1007 ($1.85 \times 10^{-3} \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$) is about one order of magnitude lower than that of PCBM ($1.04 \times 10^{-2} \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$), which should be responsible for the inferior FF of CH1007 based device.^[39,40]

To increase electron mobility of CH1007, we further blended PCBM with CH1007 at a weight ratio of 1: 1 to form CH1007: PCBM mixed layer. Besides, since PCBM has the desirable band alignment with perovskite, the more efficient electron transfer from perovskite to CH1007: PCBM can be realized (Figure 2a). As expected, the FF was significantly increased to 80.91%, resulting in a PCE of 22.75% for the device based on the CH1007: PCBM blended layer (Figure S10, Supporting Information). However, due to the absence of proper molecular heterojunctions (i.e., donor–acceptor interfaces) to provide sufficient driving force for splitting excitons, the maximum photo-response (at $\sim 860 \text{ nm}$) from CH1007 is limited to below 20%, as shown in the external quantum efficiency (EQE) spectrum (Figure S10, Supporting Information).^[41] Moreover, since part of the longer wavelength photons will be inevitably absorbed by CH1007, the low exciton splitting efficiency of PCBM: CH1007 restrains the photocurrent build-up, leading to undesired EQE

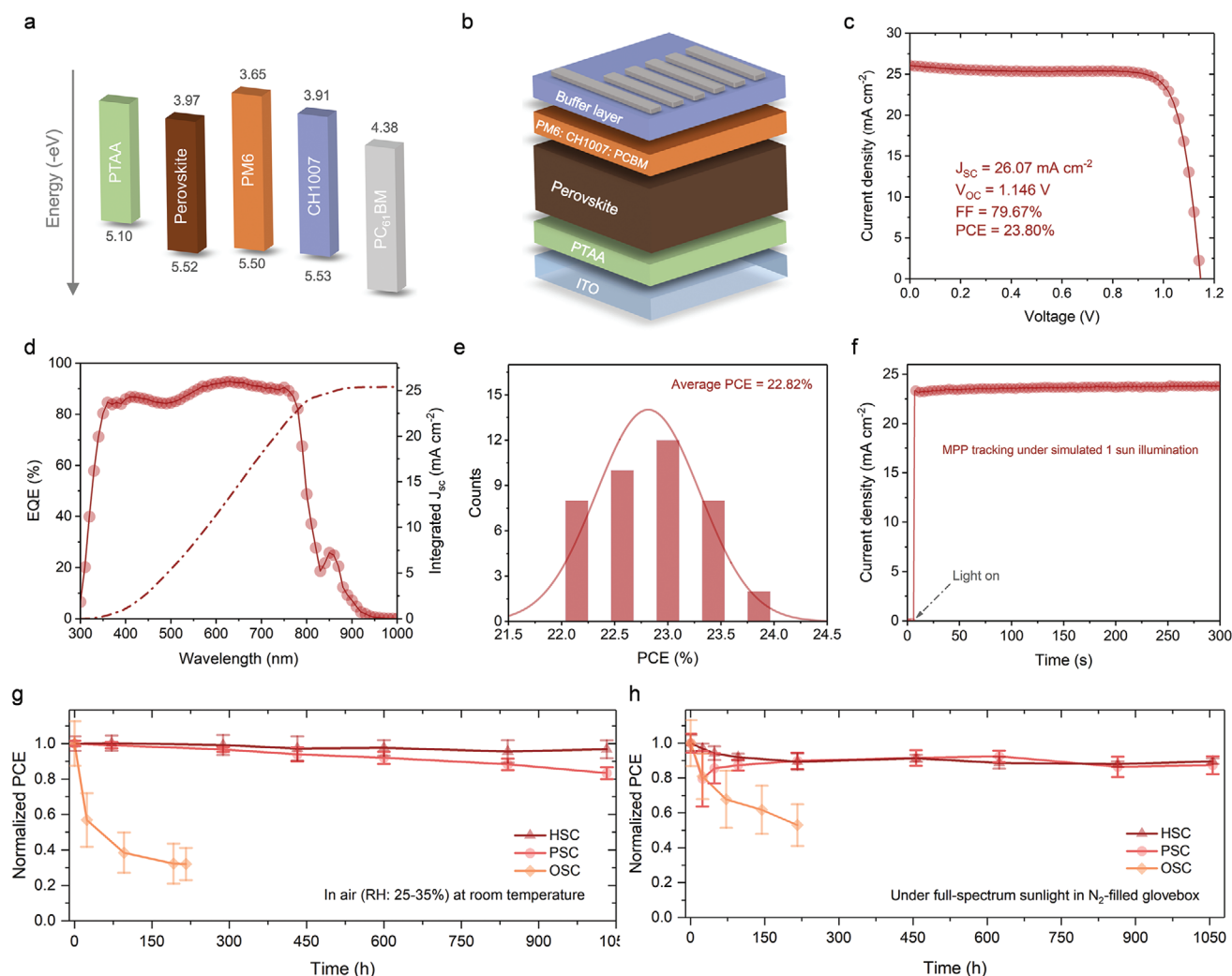


Figure 2. a) The energy level diagram and b) device structure of hybrid solar cell (HSC). c) Typical current density–voltage (*J*–*V*) characteristics and d) external quantum efficiency (EQE) spectrum of HSC. e) Power conversion efficiency (PCE) histogram and f) stabilized photocurrent tracked at its maximum power point (MPP). g) Long-term stability of the encapsulated devices aged under ambient and h) continue light illumination with 1 sun equivalent intensity.

loss between 600 and 800 nm. The similar phenomenon was also observed in the previous study where Y6 is employed as a single component ETL for inverted PSCs.^[34]

To alleviate this loss, a small quantity of PM6 donor was blended with PCBM: CH1007 to form a ternary organic BHJ and then integrated with the perovskite layer to construct an HSC, as depicted in Figure 2b; and Figure S11 (Supporting Information). To investigate the surface morphology of BHJ layer, top-view scanning electron microscopy (SEM) and atomic force microscopy (AFM) images of perovskite, perovskite/PCBM, and perovskite/BHJ were conducted and compared, as shown in Figures S12 and S13 (Supporting Information). It can be seen that the morphology is dominated by perovskite, probably due to the thin organic layers. However, the surface roughness is evidently decreased from 15.3 nm for perovskite to 6.7 nm for perovskite/PCBM and 7.6 nm for perovskite/BHJ, respectively, implying the uniform coverage of organic layers that fill the grain boundaries. Besides, the AFM phase images also implied that the perovskite is coated by PCBM or BHJ layer because of the changed signals of energy dissipation (Figure S13, Supporting Information).

As the result, the PCE was further improved from 22.75% to 23.80% (with a J_{SC} of 26.07 mA cm^{-2} , a V_{OC} of 1.146 V, and an FF of 79.67%) with negligible hysteresis, which is among the highest efficiencies for both inverted PSCs and HSCs so far (Figure 2c; and Figure S14 and Table S2, Supporting Information). Meanwhile, the EQE decrease was also prevented when PM6 was added as a third component, implicating enhanced driving force for exciton dissociation in CH1007 (Figure 2d). The J_{SC} extracted from the current density–voltage (*J*–*V*) curve matched well with the integrated value derived from the EQE spectrum. To clearly elucidate the efficacy of incorporating low-bandgap BHJ to extend the absorption of PSCs, the EQE difference ($EQE_{HSC} - EQE_{PSC}$) is presented in Figure S15 (Supporting Information), which show efficient photon utilization in the range of 800–950 nm which agrees well with the absorption spectra and simulated E-field intensity distribution. The HSCs based on other perovskite photosensitive layer also exhibited an impressively enhanced efficiency with the extended absorption and similar photovoltage, demonstrating that our strategy is generally applicable to different perovskite compositions (see

Figure S16, Supporting Information). For comparative purpose, the perovskite devices based on PM6: CH1007 and PM6: PCBM mixed layer, and OSCs based on PM6: CH1007: PCBM active layer were also provided in Figures S17 and S18 (Supporting Information).

The PCE histogram shows an average PCE of 22.82%, demonstrating high reproducibility for the fabricated HSCs (Figure 2e). The key photovoltaic parameters are also summarized in Figure S19 and Table S3 (Supporting Information), showing the device performance based on different organic layers or blends. Compared with the PSCs, the average V_{oc} of HSCs is slightly increased which might be ascribed to the interaction of the electron-rich functional groups (e.g., C=O, C–F) on PM6 and CH1007 with the undercoordinated Pb^{2+} at perovskite surface to reduce the trap state density and nonradiative recombination.^[32–34] To prove our assumption, we have performed light-intensity dependent $J-V$ measurements for both PSC and HSC. Figure S20 (Supporting Information) shows the power-law dependence of the J_{sc} on light intensity ($J_{sc} \propto I^\alpha$), and the exponential factor α was fitted to be 0.96 and 0.97 for PSC and HSC, respectively, which are close to unity, indicating that the bimolecular recombination is highly restrained in both devices.^[42] On the other hand, the ideality factor n is decreased from 1.88 for PSC to 1.69 for HSC by analyzing the slope of V_{oc} versus natural logarithm of I , which indicates that the trap-assisted Shockley–Read–Hall (SRH) recombination is suppressed in HSCs.^[43] These results verify that the perovskite/BHJ interface would not introduce additional recombination loss, instead, the BHJ layer can act as an efficient passivation agent for perovskite surface.

The champion HSC was also held at its maximum power point (MPP) with a bias voltage of 0.98 V under 1 sun continuous illumination (AM 1.5G, 100 mW cm^{−2}), which obtained a photocurrent of 23.62 mA cm^{−2} corresponding to a stabilized power output (SPO) of 23.15% (Figure 2f). These results demonstrate the importance of using ternary organic BHJ to simultaneously extend absorption range, achieve efficient charge extraction, and enhance exciton splitting for HSCs. It is noteworthy that higher content of polymer donor will further increase photocurrent, nevertheless, it will also lead to a “S” shaped $J-V$ curve, which is likely resulted from nonideal charge transfer at the perovskite/BHJ interface (Figure S21, Supporting Information).^[31] Although the underlying mechanism for this phenomenon warrants more in-depth analysis and design of suitable donor/acceptor materials, it is beyond the scope of current study.

The long-term ambient stability of HSCs was investigated by aging the encapsulated devices in air with a relative humidity (RH) of 25–35% at 25 °C. As shown in Figure 2g, the HSCs could retain 96.78% of their initial values after being stored in air for 1000 h, while the PCE of the control PSC dropped to 83.31%. The enhanced ambient stability can be attributed to the hydrophobic long alkyl chains in CH1007 and the intrinsically hydrophobic PM6 polymer network in organic BHJ that help protect the perovskite layer from being attacked by moisture in the environment.^[26,34,44] To further illustrate the protection effect of BHJ on perovskite, the film stability was carried out in humid air, as shown in Figure S22 (Supporting Information). Moreover, the ambient stability of pure OSC with the

similar blend was also assessed using the device configuration of ITO/poly(3,4-ethylenedioxythiophene) polystyrene sulfonate (PEDOT: PSS)/PM6: CH1007: PCBM/poly(9,9-bis(3'-(N,N-dimethyl)-N-ethylammonium-propyl-2,7-fluorene)-alt-2,7-(9,9-dioctylfluorene))dibromide (PFN-Br)/Ag. However, its PCE degraded rapidly to ≈30% of its initial value after being aged for over 200 h due to the strong hygroscopicity and acidity of PEDOT: PSS layer.^[45]

For future large scale deployment, the photostability of devices was also evaluated in order to have reliable PV technology. The long-term photostability of HSCs, PSCs, and OSCs was examined under continuous white light-emitting diode (LED) illumination with 1-sun equivalent intensity in an inert atmosphere (with < 5 ppm of O₂ and H₂O), as depicted in Figure 2h. After being illuminated for over 1000 h, the efficiencies of HSC and PSC decreased slightly to 89.56% and 87.36% of their initial values, respectively. In comparison, the PCE of OSC dropped more than 40% within 200 h of illumination. The inferior photostability of OSC might be due to the degradation of NFAs induced by high-energy photons, which led to increased charge traps.^[46] On the contrary, the high-energy photons (i.e., with low penetration depth) should be absorbed by the perovskite layer which acts as a screen for sun light in HSC to preserve the organic BHJ and improve its photostability. These results show great potential of HSC with improved long-term stability than those from only single component PSC and OSC counterparts.

To take advantage of the low temperature processability and extended absorption of HSCs, flexible devices were also fabricated on ITO-coated polyethylene naphthalate (PEN) substrate, as shown in Figure 3a, using the same configuration employed for the rigid devices. Figure 3b–c presents the typical $J-V$ characteristics and EQE spectrum of the champion flexible HSC, with a PCE of 21.73% (a J_{sc} of 24.82 mA cm^{−2}, a V_{oc} of 1.127 V, and an FF of 77.68%) and negligible hysteresis, which is the highest efficiency for perovskite based flexible solar cells reported to date (Figure S23, Supporting Information). To have a head-to-head comparison, the efficiencies of state-of-the-art rigid HSCs and flexible PSCs fabricated with different approaches are summarized in Figure S24 (Supporting Information). The SPO at MPP was also tracked in N₂-filled glovebox that confirm the reliability of the measured efficiency (Figure S25, Supporting Information).

Considering that significant numbers of flexible sensors might be used in the Internet of Things (IoT) ecosystem, we also tried to integrate the flexible solar cells with a temperature sensor to demonstrate self-powered on-body evaluation.^[47,48] The whole system was assembled on a polydimethylsiloxane (PDMS) substrate, as depicted in the inset of Figure 3d; and Figure S26 (Supporting Information). To assess the reliability of the integrated device, repetitive light on-off switching test were performed and the temperature data read via sensor can be expediently collected by smart phones with Near Field Communication (NFC) that allow phone to act as an NFC card reader. The integrated device exhibits good operational reliability and maintains stable monitoring of the body temperatures between 35 and 37 °C throughout 4 cycles of light on-off switching. This demonstrates that flexible HSCs can be a promising alternative power source for IoT to surpass the current market-dominating inorganic PVs because of their low-cost and high efficiencies.

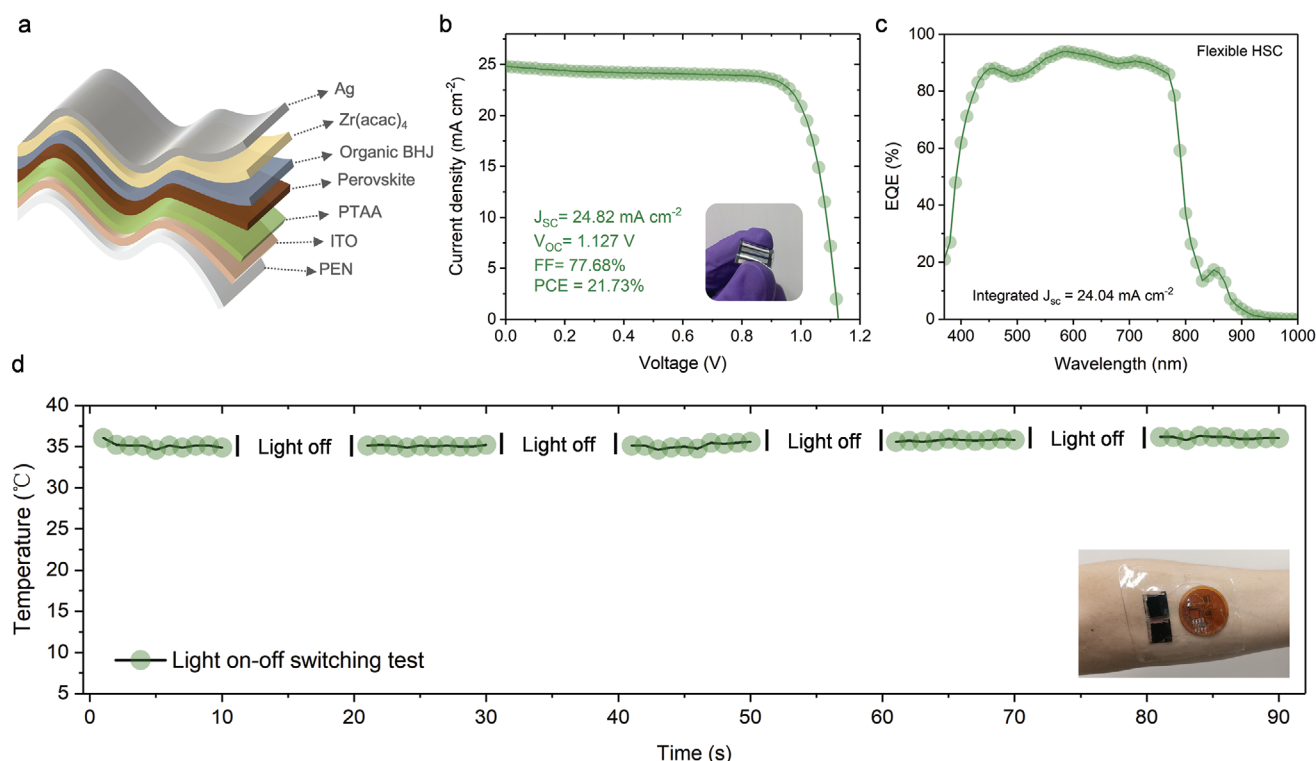


Figure 3. a) Device structure of flexible hybrid perovskite solar cell. b) Typical current density–voltage (J – V) characteristics and c) external quantum efficiency (EQE) spectrum of flexible HSC. d) Repetitive light on–off switching test for flexible solar cell–temperature sensor integrated device. The inset is the picture of the integrated device.

Figure 4a presents the efficiency variations during mechanical bendings applied to flexible HSCs with different radii (r , from 400 to 4 mm) of curvature with the schematic of cyclic bending test shown in Figure S27 (Supporting Information). There is no significant efficiency decrease found for flexible HSCs, which maintained 94% of its initial efficiency even when r is as small as 4 mm. Meanwhile, to probe the potential side effect of applied strains from different directions on the device mechanical stability, we also monitored the PCE evolution of flexible HSCs in all parallel, vertical, and diagonal bending directions during 1000 consecutive bending cycles (with a fixed r of 5 mm), as shown in the insets of Figure 4b–d. The tests were interrupted periodically in order to measure the J – V characteristics of the flexible HSCs.

Very encouragingly, no obvious efficiency decrease could be found after the devices been bent for 1000 times in parallel, vertical and diagonal directions, with the PCEs maintain $\approx 97\%$, 94% , and 98% of their initial values, respectively. It is well-known that small-molecule NFAs or fullerenes are prone to crystallization with lower intrinsic flexibility, while entangled polymer chain tends to form amorphous network that can potentially strengthen the molecular interconnection thus withstand greater mechanical deformation.^[49] Therefore, we speculated that PM6:CH1007:PCBM ternary blends can afford better mechanical robustness than that with only a PCBM single layer. To verify our hypothesis, the mechanical bending test was accordingly conducted for control flexible PSC (Figure S28, Supporting Information). The efficiencies were decreased to $< 85\%$ after 1000 times bending for all directions, which validate that PM6 network can

effectively improve the mechanical stability of BHJ layer. On the other hand, to simulate the real-life scenarios, mechanical bending test for the integrated flexible HSC–temperature sensor device was also carried out under continuous illumination. As shown in Figure 4e, the integrated device also showed good resistance to the mechanical bending after 4 repeated cycles.

3. Conclusion

In summary, we have demonstrated high-performance HSCs that can outperform both single component perovskite and organic counterparts when a PM6:CH1007:PCBM ternary blend was introduced on top of the perovskite layer to enable extended absorption for higher J_{sc} . It leads to a champion PCE of 23.80% and 21.73% for the rigid and flexible HSC, respectively, which are among the highest PCEs for inverted devices. The hybrid structure also helps enhance long-term stability under ambient (in air with RH of 25–35%) and continuous 1 sun illumination (in an inert atmosphere) for over 1000 h. Meanwhile, the flexible HSCs exhibit high mechanical-fatigue endurance with $\approx 95\%$ of the initial PCE retained after 1000 cycles of consecutive bendings. A self-powered temperature monitoring system was successfully demonstrated by integrating flexible HSCs with a wearable temperature sensor. While the flexible perovskite/organic BHJ HSC is demonstrated for proof-of-concept, this study underlines the bright prospect of employing hybrid systems as a generally applicable strategy for various optoelectronic applications.

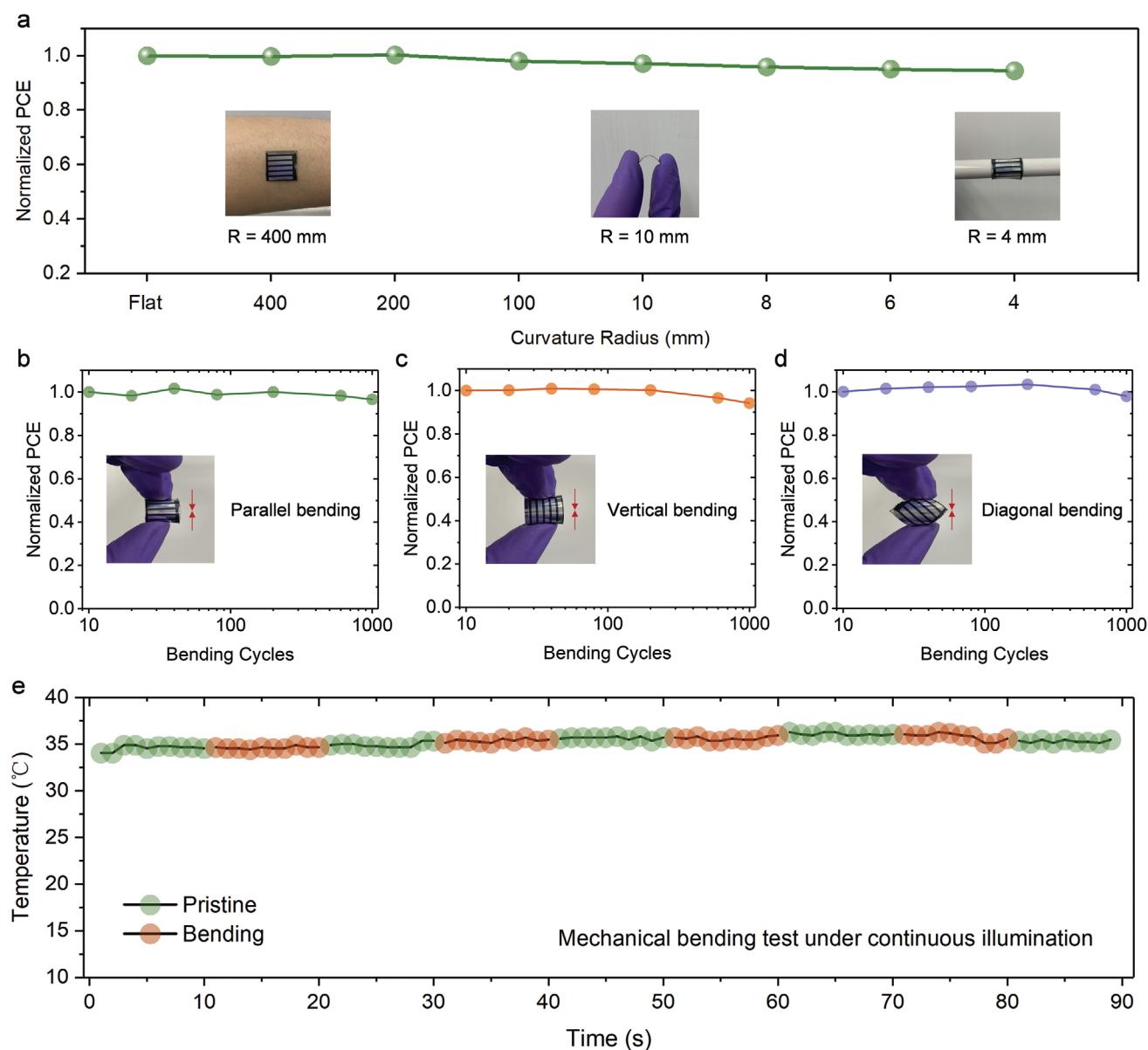


Figure 4. a) PCE variance of flexible HSC during mechanical bending test with different curvature radii. b–d) Efficiency evolution of flexible HSCs as a function of mechanical bending cycles with different bending directions and r is fixed at 5 mm. e) Mechanical bending test for integrated device under continuous illumination.

Supporting Information

Supporting Information is available from the Wiley Online Library or from the author.

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Conflict of Interest

The authors declare no conflict of interest.

Data Availability Statement

Research data are not shared.

Keywords

flexible, hybrid solar cells, organic bulk heterojunction, perovskite, wearable sensor

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