

COLLOIDAL QUANTUM DOT PHOTOVOLTAICS

A bridge for charge carriers

Obtaining simultaneously high power conversion efficiency and long-term stability in organic blend/quantum dot solar cells is considered a tough challenge. Now, realization of a hybrid architecture that exploits the addition of a small molecule brings researchers a step closer to overcoming it.

Daniele Benetti and Federico Rosei

In the past decade, photovoltaics (PV) has emerged as one of the most credible eco-friendly alternatives to fossil fuels for electricity generation¹. Silicon-based PV devices have reached remarkable power conversion efficiencies (PCE), up to 26%, together with a more than 25 year lifetime. However, due to the intrinsically opaque and rigid nature of silicon cells, they cannot satisfy the requirements for integration into growing markets such as windows on buildings, electrical vehicles and the internet-of-things, among others. In addition, the fabrication of silicon solar cells is an energy-intensive process and generates large amounts of waste. On the other hand, hybrid PV technologies based on perovskites, organics and colloidal quantum dot (QD) materials, are considered promising because they can be processed inexpensively at ambient conditions. In particular, these materials can be deposited with roll-to-roll techniques to realize large area, semi-transparent and flexible devices^{2,3}.

Hybrid PV devices based on blending colloidal QDs and organic conductive polymers combine the best of both worlds: the ease of processability and recyclability of the polymers⁴ with the outstanding optoelectronic properties of QDs, such as size-dependent absorption and emission, and energy level structure⁵. Since the first hybrid QD/organic polymer proof-of-concept devices^{6,7}, significant progress has been achieved by extending the absorption range of the device to the near infrared by combining complementary absorption spectra. So far, due to poor charge transfer and carrier extraction efficiencies, the PCE of such solar cells has yet to reach 10% and has lagged behind the performance of single organic or QD solar cells^{8–10}. Now, writing in *Nature Energy*, Edward Sargent and colleagues in Canada, South Korea and the USA report a hybrid device that exhibits an extraordinary efficiency of 13.1%, a record among these kinds of devices, combined with an excellent operating stability of over 150 h¹¹.

The researchers introduced a low band gap non-fullerene small molecule in the

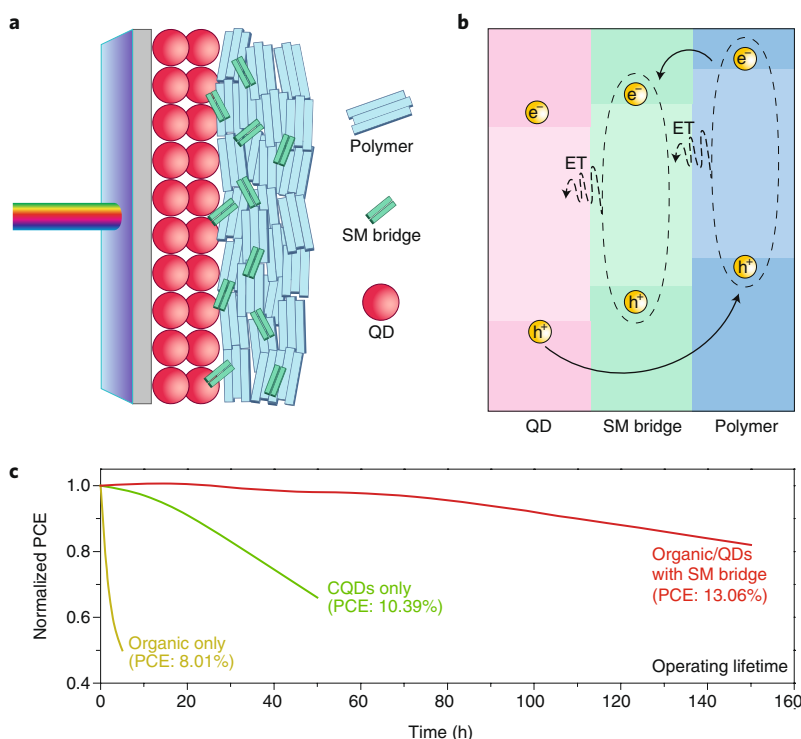


Fig. 1 | The bridge effect of small molecules in hybrid colloidal QD/polymer solar cells. a, Schematic of the hybrid QD/polymer structure with the small molecule (SM) bridge deposited over a substrate (grey/blue layers). Light enters the stack from the QD side. **b**, Charge transfer (CT) and energy transfer (ET) mechanism inside the cell that promotes exciton (dashed oval) funnelling and electron/hole separation at the QD/polymer interface. These processes are mediated by the SM bridge thanks to type II energy level alignment. **c**, Operating lifetime of organic only (yellow), QD only (green) and organic/QDs with SM bridge (red) devices. Initial device efficiency is given in brackets. QDs, colloidal quantum dots. Panel **c** is adapted from ref. ¹¹, Springer Nature Ltd.

polymer layer and deposited the blend on top of a colloidal lead sulfide QD thin film (Fig. 1a). This bilayer architecture presents multiple advantages. First, the small molecule absorbs in the near infrared between 650–850 nm thus complementing the absorption of the host polymer in the visible range and that of the QD film, above 850 nm. Enhanced absorption in the near infrared region leads to a twofold enhancement in external quantum efficiency due to higher generation of carriers. This

translates into an increase of the short circuit current density from 13 to 23 mA cm⁻². Second, it improves the charge dynamics inside the solar cell by creating an exciton cascade with the host polymer, enabling efficient energy transfer and promoting exciton dissociation at the interface (Fig. 1b). Due to the formation of a staggered type II band alignment between QDs and organic layers, electrons will transfer from the polymer to the QDs and the holes will move in the opposite direction, with a preferential

transfer from the QDs into the polymer. The small molecule acts as a bridge between the polymer and the QDs, acting as an energy funnel that allows excitons to migrate from the polymer to the QDs layer. In addition, it behaves as electron acceptor, reducing the recombination inside the polymer.

A solar cell, to be economically viable, should offer high efficiency combined with low cost as well as an extended lifetime. The clever design presented by Sargent and colleagues offers a further advantage beyond high efficiency: an intrinsic encapsulation that improves stability, as the QDs film is protected from moisture and oxygen by the organic layer. In addition, as light enters the bottom of the device (through a transparent conductive oxide glass), higher-energy photons are first absorbed in the QDs film, reducing the UV-induced photodegradation of the organic film. The combined effect results in a superior stability of the cell: more than 80% of the initial performance is retained after 150 h under the most stringent conditions, that is, solar cell biased at the maximum power point (Fig. 1c). This stability is even more impressive considering that it is obtained

under standard atmosphere, without a UV filter and encapsulation.

Overall, the work reported by Sargent and team demonstrates that the addition of a small molecule bridge to the host polymer blend simultaneously improves photovoltaic performance and has a synergistic benefit on both storage lifetime and photostability in ambient air. These results represent a substantial advantage compared to previous similar devices. While hybrid PV solar cells are still far from being viable for commercial applications, the strategy reported by the researchers could be applicable to new combinations of polymer blends and QDs, in which charge transfer, transport and light management in the active layers can be finely tuned to achieve better performances. A deeper understanding of issues such as the role of ligands in the charge dynamics and the control of morphology of the polymer blends to realize larger scale films, are needed to deploy high efficiency and stable hybrid PV as commercial technologies. In addition, even if hybrid PV solar cells will not be able to reach the required standard 25 years lifetime, it does not mean that they cannot be commercially competitive. In fact, recent work has highlighted that emerging

PV technologies with lifetimes shorter than 25 years could still be cost effective, since solar panels become more efficient and cost effective over time, so that periodically replacing panels may become economically advantageous¹². □

Daniele Benetti^{ID} and Federico Rosei^{ID*}

Centre for Energy, Materials and Telecommunications, Institut National de la Recherche Scientifique, Varennes, Quebec, Canada.
*e-mail: rosei@emt.inrs.ca

Published online: 11 November 2019
<https://doi.org/10.1038/s41560-019-0499-7>

References

- Green, M. A. *Nat. Energy* **1**, 15015 (2016).
- Li, Z. et al. *Nat. Rev. Mater.* **3**, 18017 (2018).
- Zhou, Y. et al. *Adv. Energy Mater.* **6**, 1501913 (2016).
- Lu, L. et al. *Chem. Rev.* **115**, 12666–12731 (2015).
- Navarro-Pardo, F., Zhao, H., Wang, Z. M. & Rosei, F. *Acc. Chem. Res.* **51**, 609–618 (2018).
- Greenham, N. C., Peng, X. & Alivisatos, A. P. *Phys. Rev. B* **54**, 17628–17637 (1996).
- Huynh, W. U., Dittmer, J. J. & Alivisatos, A. P. *Science* **295**, 2425–2427 (2002).
- Cui, Y. et al. *Nat. Commun.* **10**, 2515 (2019).
- Aqoma, H. et al. *Adv. Energy Mater.* **8**, 1800572 (2018).
- Xu, J. et al. *Nat. Nanotechnol.* **13**, 456–462 (2018).
- Baek, S.-W. et al. *Nat. Energy*. <https://doi.org/10.1038/s41560-019-0492-1> (2019).
- Jean, J., Woodhouse, M. & Bulović, V. *Joule*. <https://doi.org/10.1016/j.joule.2019.08.012> (2019).