Supporting Information

Charge-transfer induced multifunctional BCP:Ag complexes for semi-transparent perovskite solar cells with a record fill-factor of 80.1%

Zhiqin Ying,[abc] Xi Yang,[b] Jingming Zheng,[b] Yudong Zhu,[a] Jingwei Xiu,[a] Wei Chen,[a] Chunhui Shou,[d] Jiang Sheng,[b] Yuheng Zeng,[b] Baojie Yan,[b] Hui Pan,[*c] Jichun Ye,[*b] and Zhubing He[*a]

[a] Department of Materials Science and Engineering, Shenzhen Key Laboratory of Full Spectral Solar Electricity Generation (FSSEG), Southern University of Science and Technology, No. 1088, Xueyuan Rd., Shenzhen, 518055, Guangdong, China.

[b] Ningbo Institute of Materials Technology and Engineering, Chinese Academy of Sciences (CAS), Ningbo City 315201, PR China

[c] Institute of Applied Physics and Materials Engineering, University of Macau, Macao SAR, 999078 China

[d] Zhejiang Energy Group R&D, Hangzhou 310003, China

Table S1 Comparison to the state-of-the-art buffer layer/transparent conductive electrodes stacks for semitransparent perovskite solar cells.

	Buffer layer/TCEs	PCE	J_{SC} mA/cm²	V_{OC} V	*FF*	Ref
n-i-p	**MoO_x/ITO**	6.2%	14.5	0.82	0.52	[1]
	MoO_x/IZO	10.3%	17.5	0.87	0.68	[2]
	MoO_x/AZO	12.1%	16.7	1.03	0.70	[3]
	MoO_x/InOx:H	14.2%	17.4	1.10	0.73	[4]
	ITO NPs/ITO	15.1%	19.9	1.10	0.69	[5]
	MoO_x/IOH/ITO	16.4%	20.1	1.07	0.76	[6]
	MoO_x/ITO	16.7%	22.0	1.01	0.75	[7]
	Ag NPs/ITO	17.7%	21.5	1.06	0.77	[8]
	MoO_x/IZO	19.0%	22.3	1.12	0.76	[9]
p-i-n	**AZO NPs/ITO**	12.3%	16.5	0.95	0.78	[10]
	ITO	13.6%	16.7	1.08	0.75	[11]
	SnO_x/ZTO/ITO	15.8%	20.3	0.97	0.79	[12]
	ZnO NPs/ZnO/ITO	16.4%	20.3	1.07	0.76	[13]
	SnO_x/ZTO/IZO	18.2%	20.8	1.12	0.78	[14]
	BCP:Ag/IZO	18.19%	21.1	1.08	0.801	This work

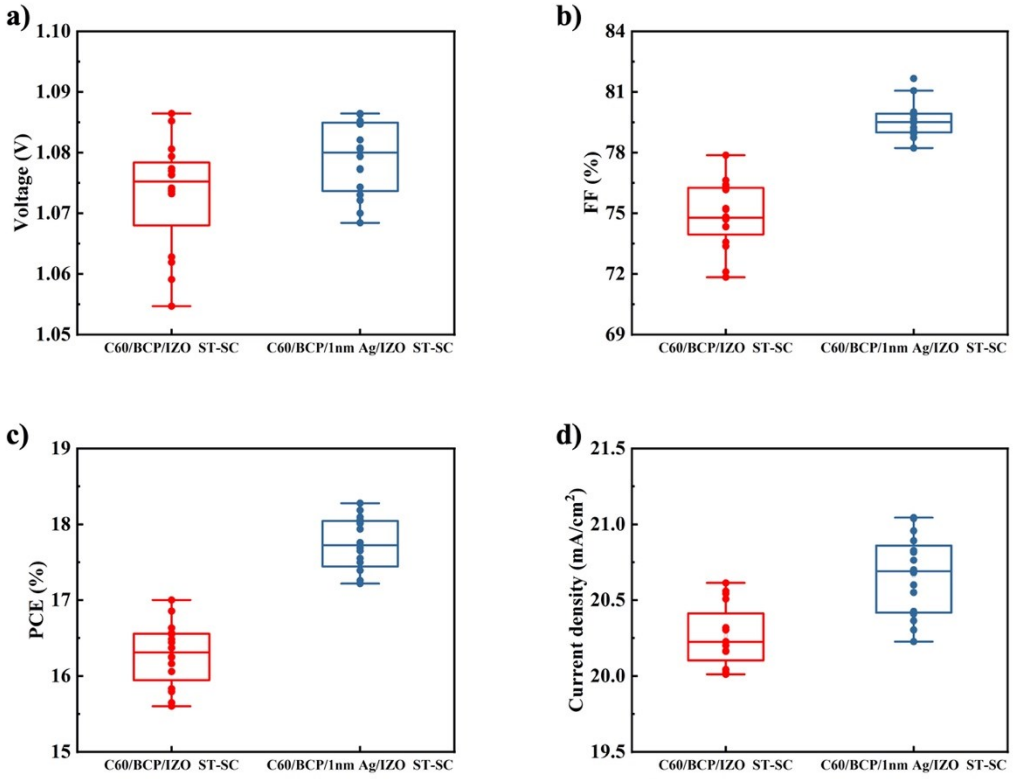

Fig. S1 The photovoltaic parameters statistics of the semi-transparent perovskite solar cell with and without Ag.

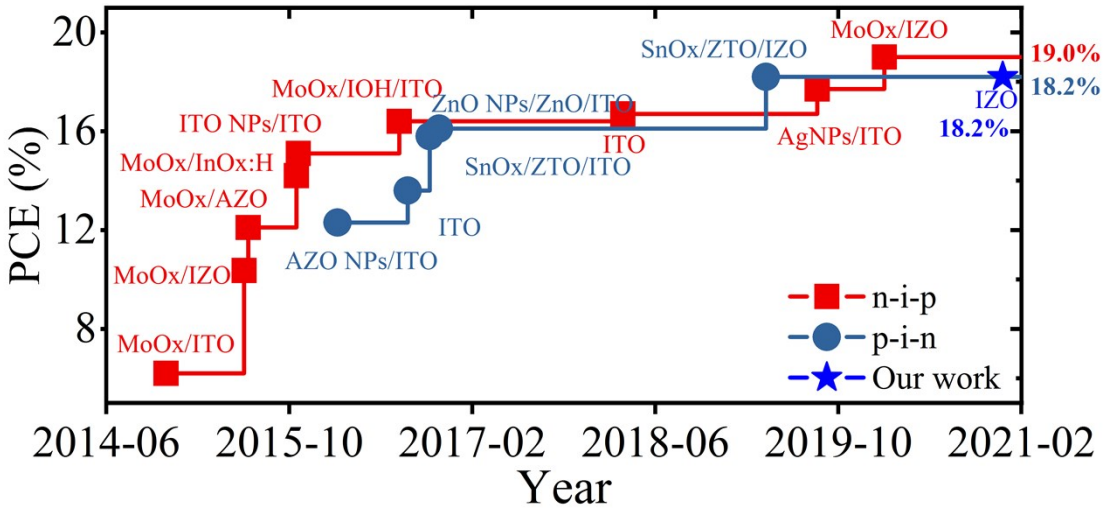

Fig. S2 The efficiency history of semi-transparent perovskite solar cell (illuminated from the glass side).

Table S2 The *J*−*V* parameters of the semi-transparent solar cells with different Ag thickness.

Ag thickness	V_{OC} **(V)**	J_{SC} **(mA/cm^2)**	***FF*** **(%)**	**PCE (%)**
0 nm	1.073	20.95	71.8	16.14
0.5 nm	1.075	21.02	78.7	17.78
1 nm	1.076	21.14	80.1	18.19
2 nm	1.076	20.99	80.0	18.06

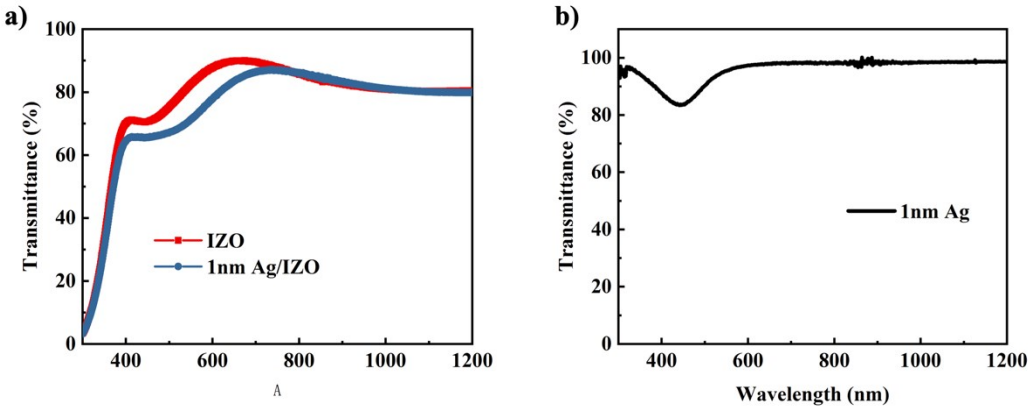

Fig. S3 a) The optical transmittance of the IZO cathodes in the wavelength range of 300-1200 nm with and without Ag layer. b) The optical transmittance of the 1nm Ag layer in the wavelength range of 300-1200 nm.

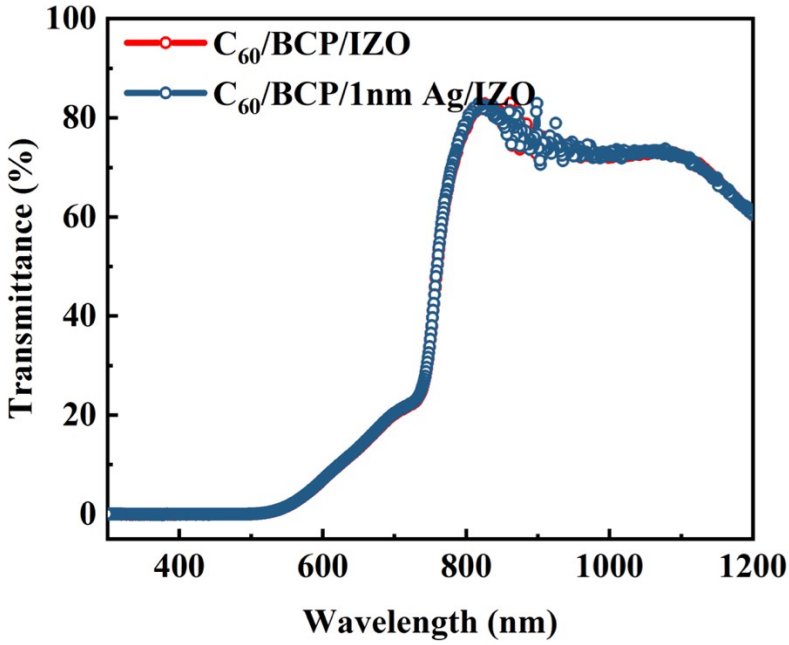

Fig. S4 The optical transmittance of the semi-transparent perovskite solar cell in the wavelength range of 300–1200 nm with and without Ag layer. The transmittance of the semi-transparent perovskite solar cell in the wavelength range between 800 nm to 1200 nm is about 73.1%

Table S3 Summary of the PL lifetime parameters from fitting curves of the PL decay measurements.

Sample	**A_1(%)**	**τ_1(ns)**	**A_2(%)**	**τ_2(ns)**	**$\tau_{Avg.}$(ns)**
PVK/C_{60}/BCP/IZO	10.73	1.76	89.27	14.68	14.48
PVK/C_{60}/BCP/Ag/IZO	26.12	0.84	73.88	8.12	7.86

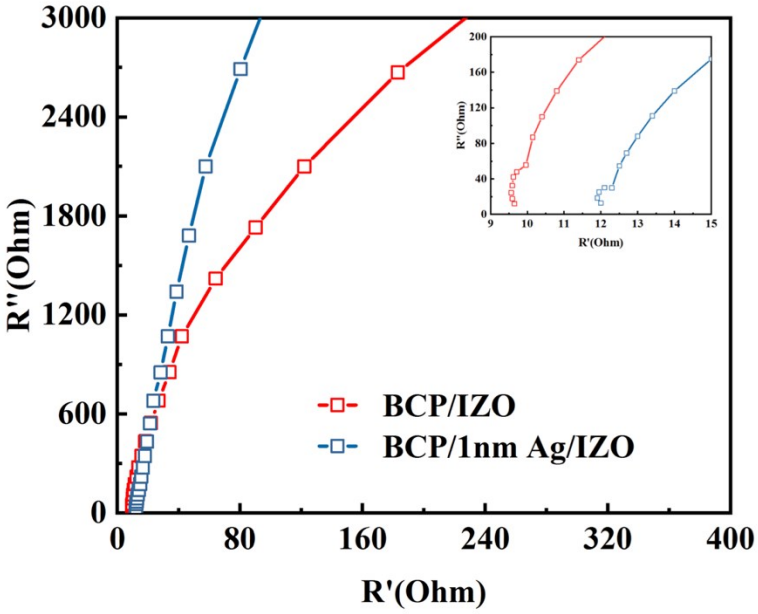

Fig. S5 Nyquist plots obtained from the electrochemical impedance spectroscopy (EIS) measurement of semi-transparent perovskite solar cells with and without Ag.

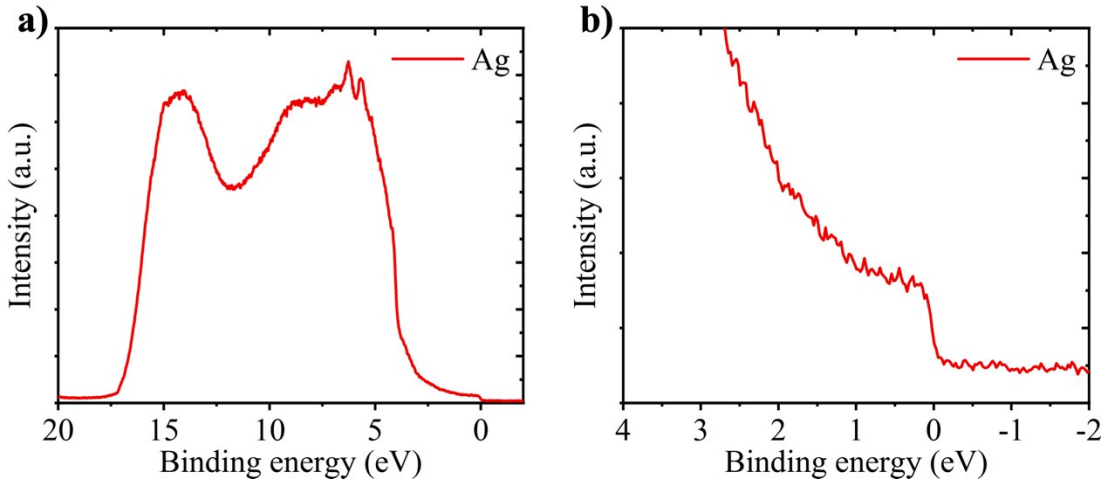

Fig. S6 a) The UPS spectrum and b) the Fermi edge for the thick Ag film

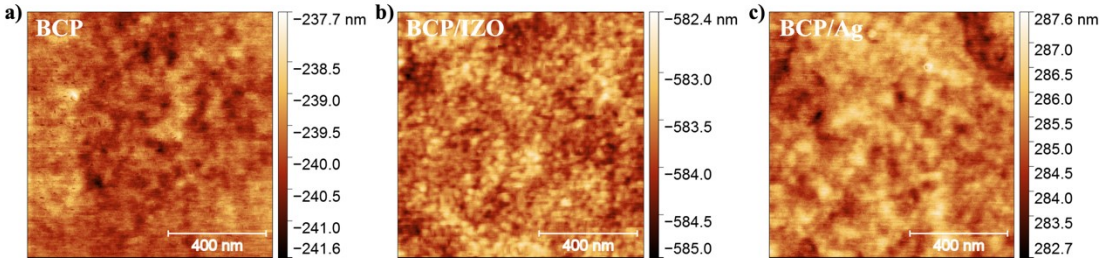

Fig. S7 The top-view AFM images of a) BCP, b) BCP/IZO and c) BCP/Ag.

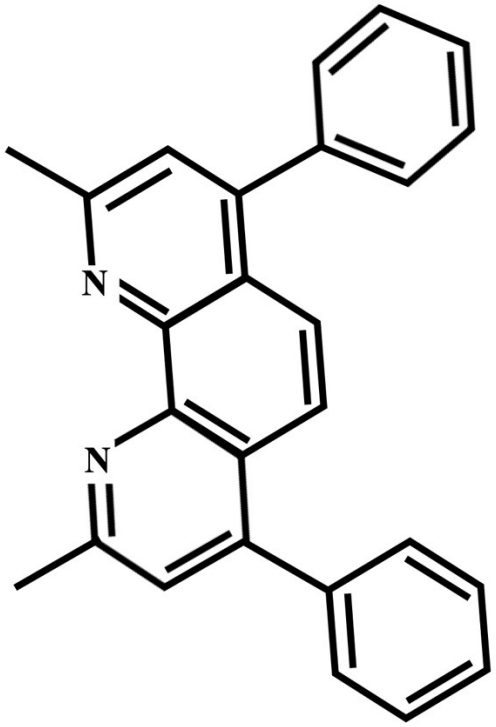

Fig. S8 The chemical structure of BCP

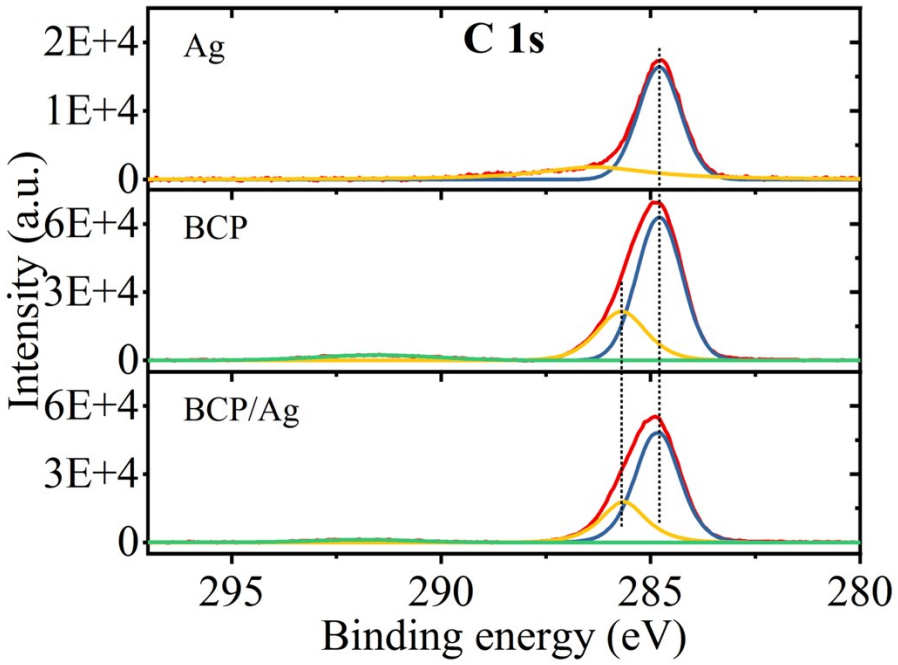

Fig. S9 The XPS high resolution spectra of C 1s for Ag, BCP and Ag/BCP.

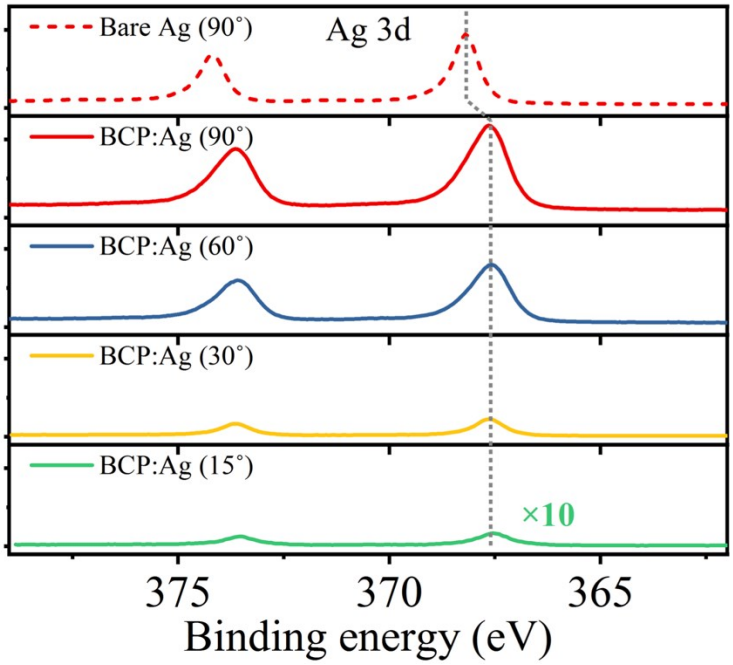

Fig. S10 The angle-resolved XPS (ARXPS) measurements with 90˚, 60˚, 30˚, and 15˚ photoelectron take-off angles for BCP/Ag. The bare Ag measurements with 90˚ was also shown as the reference.

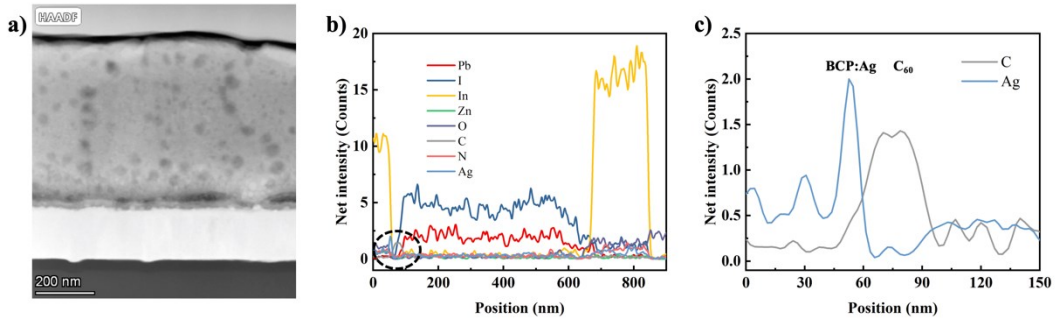

Fig. S11 a) The HAADF image and b) the corresponding depth-profiling EELS data of BCP:Ag based semi-transparent device. c) The EELS line scan across the IZO/BCP:Ag/C_{60} contact stack.

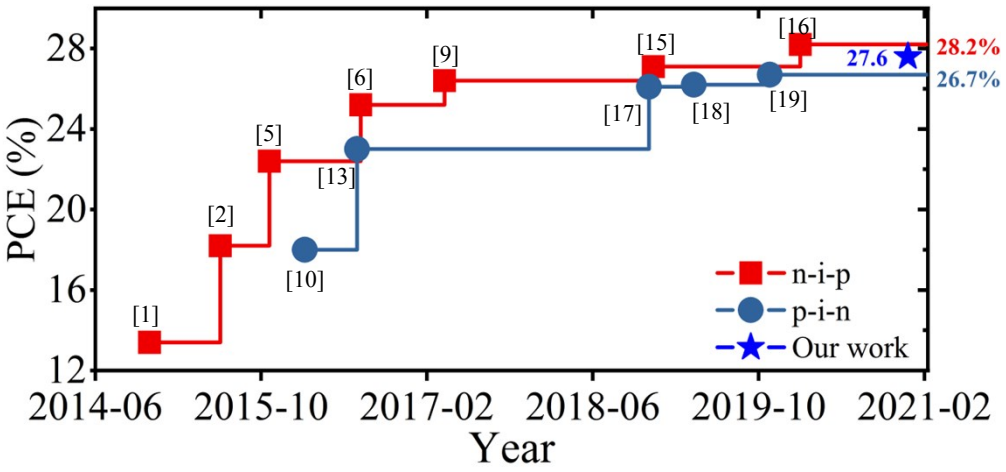

Fig. S12 The efficiency history of four terminal perovskite/Si tandem solar cell with n-i-p [39, 40, 42, 43, 45, 50, 51] and p-i-n[46, 49, 52-54].

References

[1] P. Löper, S.-J. Moon, S. Martín de Nicolas, B. Niesen, M. Ledinsky, S. Nicolay, J. Bailat, J.-H. Yum, S. De Wolf, C. Ballif, Phys. Chem. Chem. Phys. 2015, 17, 1619.
[2] J. Werner, G. Dubuis, A. Walter, P. Löper, S.-J. Moon, S. Nicolay, M. Morales-Masis, S. De Wolf, B. Niesen, C. Ballif, Sol. Energy Mater. Sol. Cells 2015, 141, 407.
[3] L. Kranz, A. Abate, T. Feurer, F. Fu, E. Avancini, J. Löckinger, P. Reinhard, S. M. Zakeeruddin, M. Grätzel, S. Buecheler, A. N. Tiwari, J. Phys. Chem. Lett. 2015, 6, 2676.
[4] F. Fu, T. Feurer, T. Jäger, E. Avancini, B. Bissig, S. Yoon, S. Buecheler, A. N. Tiwari, Nat. Commun. 2015, 6, 8932.
[5] D. P. McMeekin, G. Sadoughi, W. Rehman, G. E. Eperon, M. Saliba, M. T. Hörantner, A. Haghighirad, N. Sakai, L. Korte, B. Rech, M. B. Johnston, L. M. Herz, H. J. Snaith, Science 2016, 351, 151.
[6] J. Werner, L. Barraud, A. Walter, M. Bräuninger, F. Sahli, D. Sacchetto, N. Tétreault, B. Paviet-Salomon, S.-J. Moon, C. Allebé, M. Despeisse, S. Nicolay, S. De Wolf, B. Niesen, C. Ballif, ACS Energy Lett. 2016, 1, 474.
[7] M. Jaysankar, M. Filipič, B. Zielinski, R. Schmager, W. Song, W. Qiu, U. W. Paetzold, T. Aernouts, M. Debucquoy, R. Gehlhaar, J. Poortmans, Energy Environ. Sci. 2018, 11, 1489.
[8] H. A. Dewi, H. Wang, J. Li, M. Thway, R. Sridharan, R. Stangl, F. Lin, A. G. Aberle, N. Mathews, A. Bruno, S. Mhaisalkar, ACS Appl. Mater. Interfaces 2019, 11, 34178.
[9] B. Chen, S.-W. Baek, Y. Hou, E. Aydin, M. De Bastiani, B. Scheffel, A. Proppe, Z. Huang, M. Wei, Y.-K. Wang, E.-H. Jung, T. G. Allen, E. Van Kerschaver, F. P. García de Arquer, M. I. Saidaminov, S. Hoogland, S. De Wolf, E. H. Sargent, Nat. Commun. 2020, 11, 1257.
[10] K. A. Bush, C. D. Bailie, Y. Chen, A. R. Bowring, W. Wang, W. Ma, T. Leijtens, F. Moghadam, M. D. McGehee, Adv. Mater. 2016, 28, 3937.
[11] Z. Yang, A. Rajagopal, C.-C. Chueh, S. B. Jo, B. Liu, T. Zhao, A. K. Y. Jen, Adv. Mater. 2016, 28, 8990.
[12] G. E. Eperon, T. Leijtens, K. A. Bush, R. Prasanna, T. Green, J. T.-W. Wang, D. P. McMeekin, G. Volonakis, R. L. Milot, R. May, A. Palmstrom, D. J. Slotcavage, R. A. Belisle, J. B. Patel, E. S. Parrott, R. J. Sutton, W. Ma, F. Moghadam, B. Conings, A.

Babayigit, H.-G. Boyen, S. Bent, F. Giustino, L. M. Herz, M. B. Johnston, M. D. McGehee, H. J. Snaith, Science 2016, 354, 861.
[13] D. Zhang, M. Najafi, V. Zardetto, M. Dorenkamper, W. Verhees, X. Zhou, A. Senes, A. Gutjahr, I. Romijn, S. Veenstra, B. Geerligs, M. Creatore, T. Aernouts, R. Andriessen, presented at 2018 IEEE 7th World Conference on Photovoltaic Energy Conversion (WCPEC) (A Joint Conference of 45th IEEE PVSC, 28th PVSEC & 34th EU PVSEC), 10-15 June 2018, 2018.
[14] J. Tong, Z. Song, D. H. Kim, X. Chen, C. Chen, A. F. Palmstrom, P. F. Ndione, M. O. Reese, S. P. Dunfield, O. G. Reid, J. Liu, F. Zhang, S. P. Harvey, Z. Li, S. T. Christensen, G. Teeter, D. Zhao, M. M. Al-Jassim, M. F. A. M. van Hest, M. C. Beard, S. E. Shaheen, J. J. Berry, Y. Yan, K. Zhu, Science 2019, 364, 475.
[15] T. Duong, Y. Wu, H. Shen, J. Peng, X. Fu, D. Jacobs, E. C. Wang, T. C. Kho, K. C. Fong, M. Stocks, E. Franklin, A. Blakers, N. Zin, K. McIntosh, W. Li, Y. B. Cheng, T. P. White, K. Weber, K. Catchpole, Adv. Energy Mater. 2017, 7.
[16] M. Jaysankar, B. A. L. Raul, J. Bastos, C. Burgess, C. Weijtens, M. Creatore, T. Aernouts, Y. Kuang, R. Gehlhaar, A. Hadipour, J. Poortmans, ACS Energy Lett. 2019, 4, 259.
[17] B. Chen, Y. Bai, Z. Yu, T. Li, X. Zheng, Q. Dong, L. Shen, M. Boccard, A. Gruverman, Z. Holman, J. Huang, Adv. Energy Mater. 2016, 6, 1601128.
[18] E. Aydin, M. De Bastiani, X. Yang, M. Sajjad, F. Aljamaan, Y. Smirnov, M. N. Hedhili, W. Liu, T. G. Allen, L. Xu, E. Van Kerschaver, M. Morales-Masis, U. Schwingenschlögl, S. De Wolf, Adv. Funct. Mater. 2019, 29, 1901741.
[19] A. Rohatgi, K. Zhu, J. Tong, D. H. Kim, E. Reichmanis, B. Rounsaville, V. Prakash, Y. Ok, Ieee J Photovolt 2020, 10, 417.