Developments in solar research at TU Eindhoven

DUTCH ISRAELI RENEWABLE ENERGY CONVERSION AND STORAGE - MINI SYMPOSIUM – JANUARY 13, 2021

René Janssen

Molecular Materials and Nanosystems, Departments of Chemical Engineering & Chemistry and Applied Physics

TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY

Solar research groups at TU/e

Erwin Kessels
atomic layer deposition

Adriana Creatore
atomic layer deposition

Michael Debije
luminescent concentrators

Erik Bakkers
nanowires

Shuxia Tao
perovskites

Roel Loonen
building integrated

Angèle Reinders
solar cell design

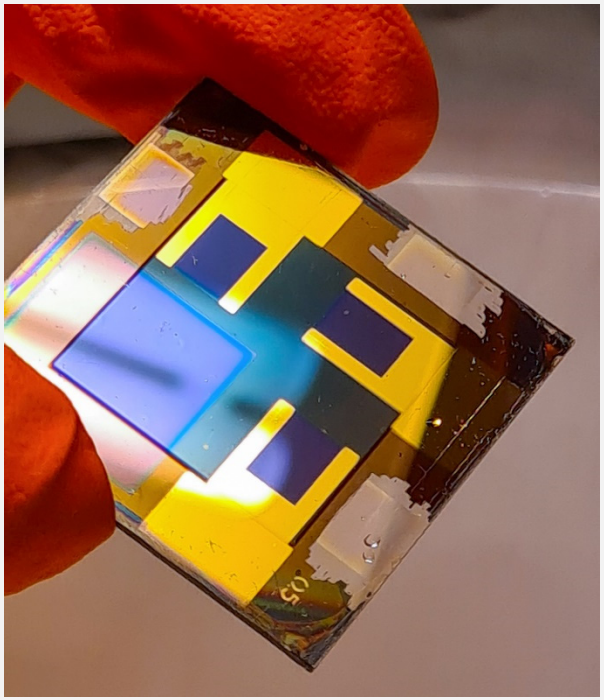
René Janssen
organic & perovskites

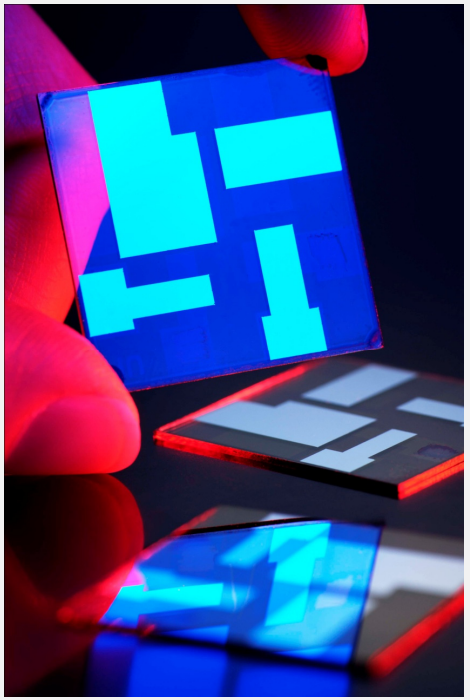
https://www.tue.nl/en/news/features/how-tue-technology-brings-the-endless-power-of-the-sun-to-your-home-and-car/

Molecular Materials and Nanosystems (M2N)

Organic solar cells
Perovskite solar cells
Solar fuels

Redox flow batteries
Polaritons in organic crystals
Organic light-emitting diodes
Photodetectors





SOLLIANCE
10 YEARS OF SOLAR RESEARCH

DIFFER
Dutch Institute for Fundamental Energy Research

www.m2ngroup.nl

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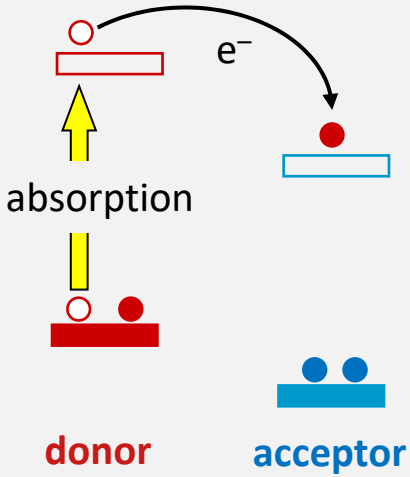
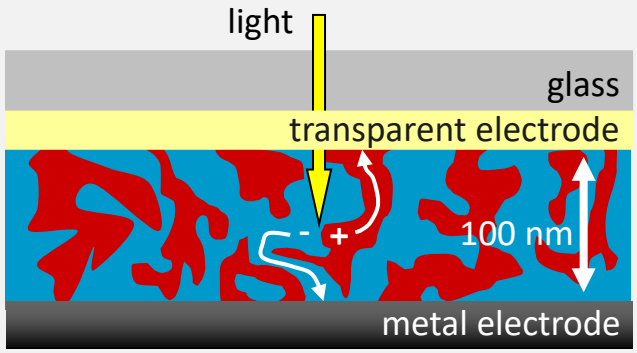
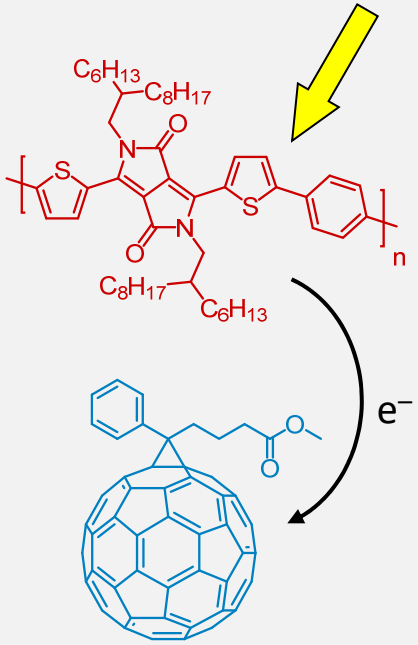
Organic bulk-heterojunction solar cells

Use two organic semiconductors with off-set energy levels

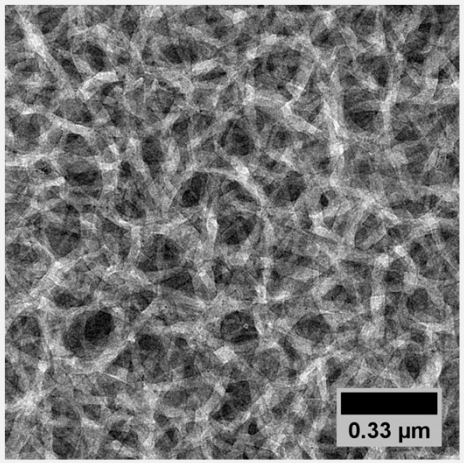


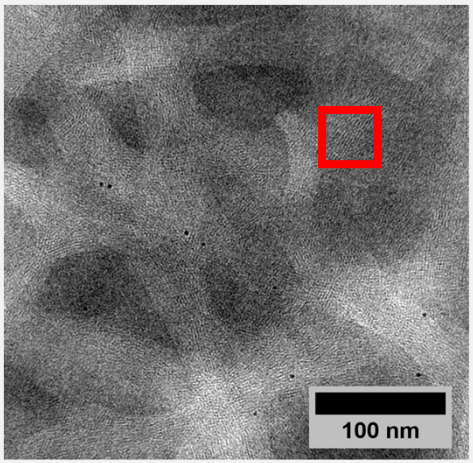


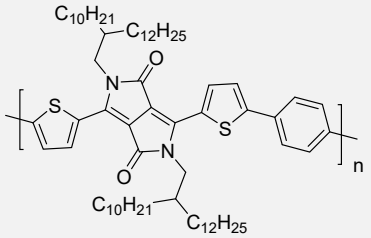


nanoscopic mixing of donor and acceptor to overcome ~10 nm exciton diffusion length

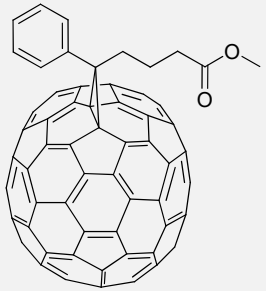
Morphology on a nanoscopic scale



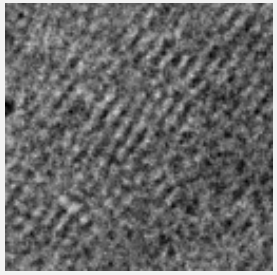


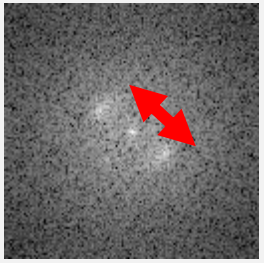


DT-PDPPTPT



[70]PCBM





lamellar stacking 2.2-2.4 nm

Hans van Franeker J. Am. Chem. Soc. **2015**, 137, 11783

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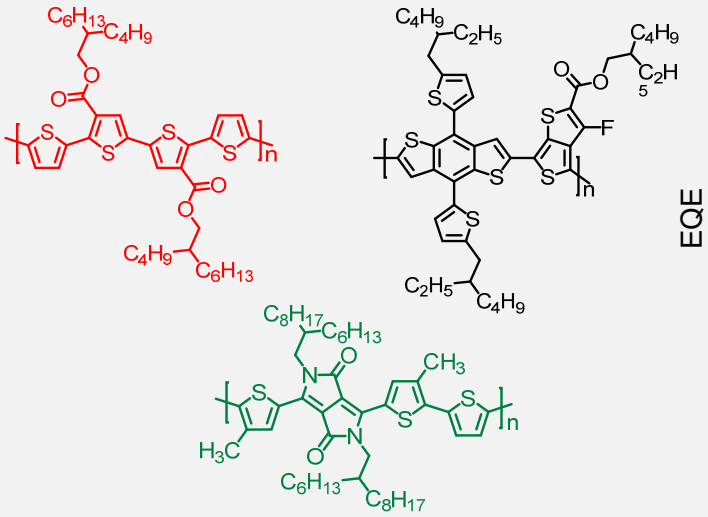
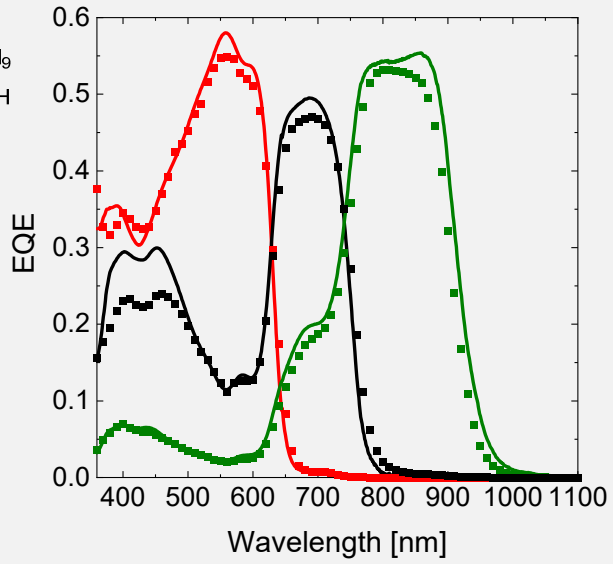
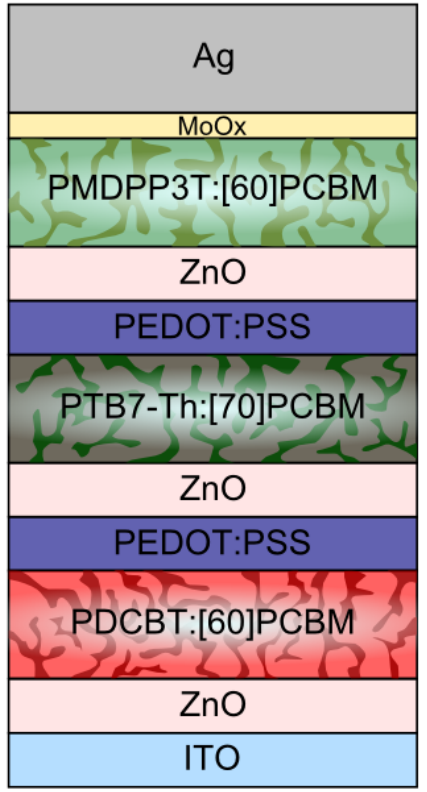
Triple-junction organic solar cells





	J_{sc} (mA cm^{-2})	V_{oc} (V)	FF	PCE (%)
Predicted	7.23	2.20	0.63	10.1
Experiment	6.75	2.17	0.68	10.0



Dario Di Carlo Rasi, Adv. Energy Mater. **2017**, 7, 1701664
& Adv. Mater. **2018**, 30,1803836

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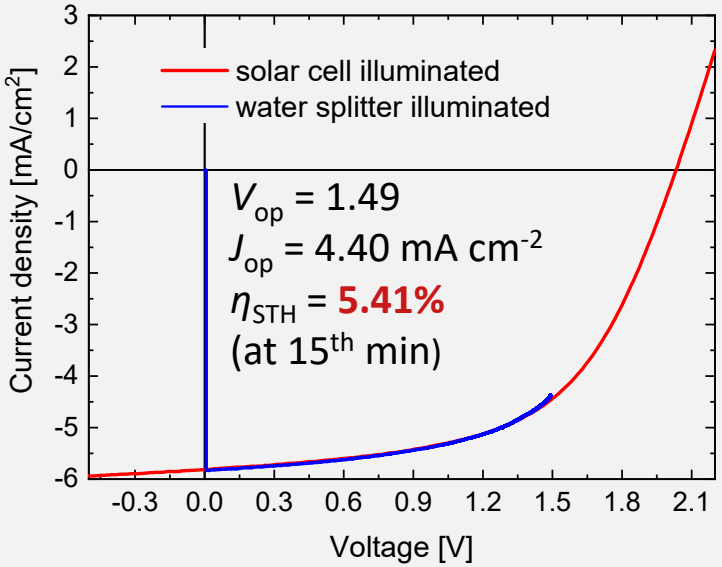
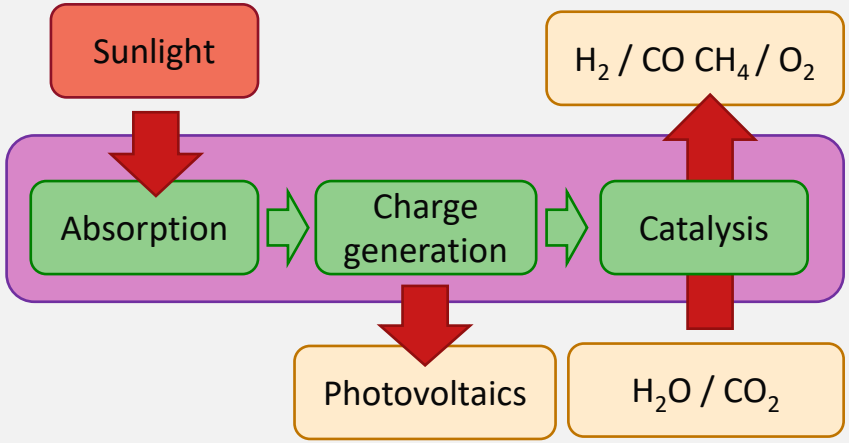
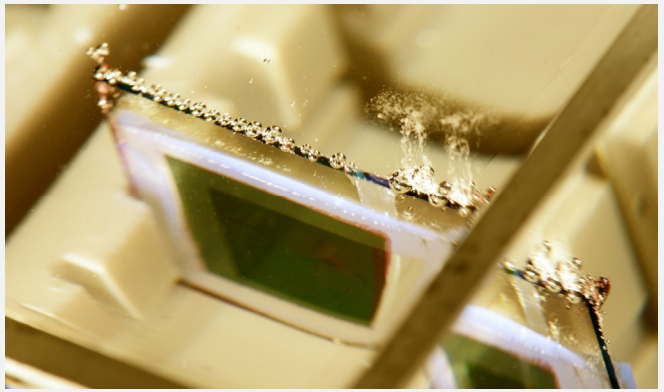
Organic solar fuel cells

Triple-junction organic solar cell
RuO_2 catalysts for H_2 and O_2 evolution







Serkan Esiner, J. Mater. Chem. A **2015**, 3, 23936

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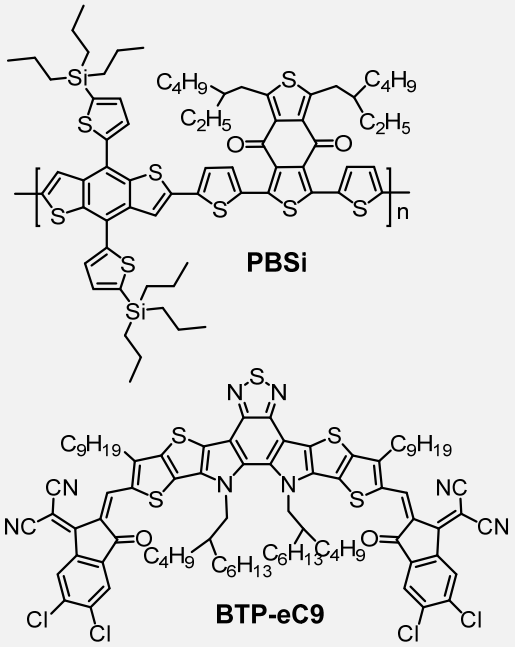
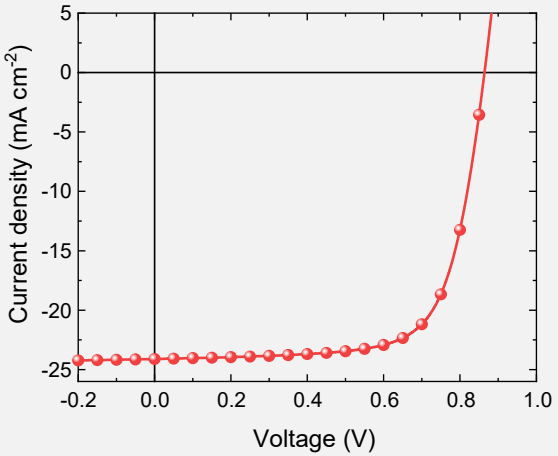
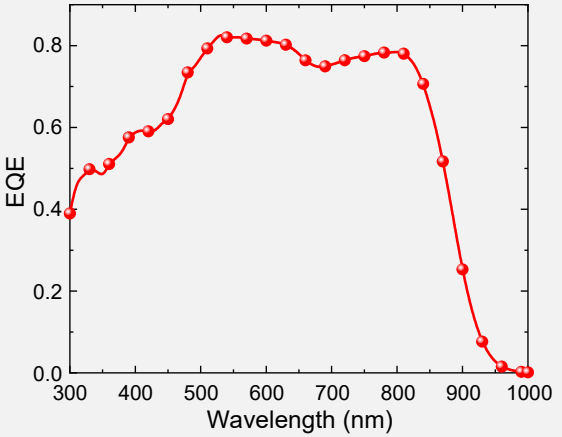
High-efficient organic solar cells



J_{sc} (mA cm^{-2})	V_{oc} (V)	FF	PCE (%)
24.6	0.86	0.72	15.2

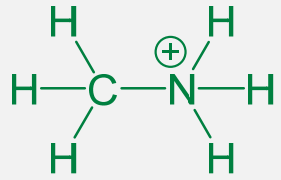




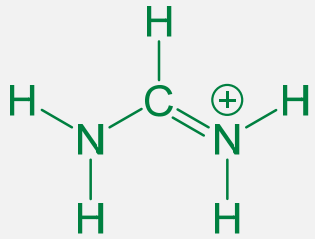
Haijun Bin, to be published

ABX_3 perovskites for solar cells

A



Methylammonium (MA)

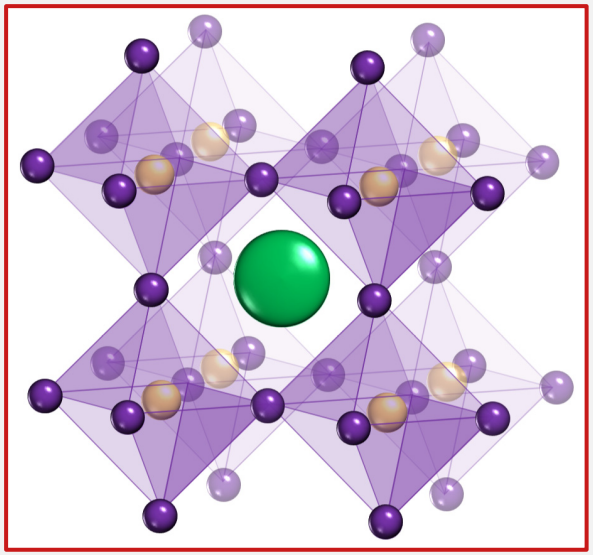


Formamidinium (FA)

Cs+ Rb+

B Pb^{2+} Sn^{2+}

X Cl^- Br^- I^-



Tolerance factor:

$$t = \frac{R_A + R_X}{\sqrt{2}(R_M + R_X)}$$

R_A and R_B and R_X are the radii of the ions

For a cubic perovskite: $0.78 < t < 1.05$

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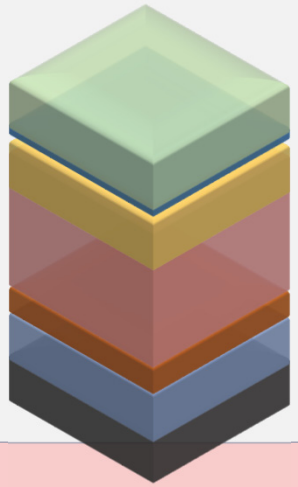
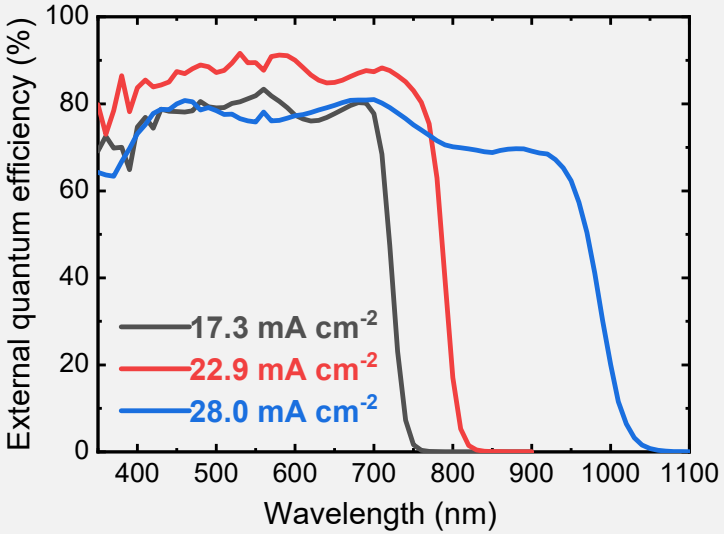
Band gap tuning



Top contact
Electron transport layer

Perovskite

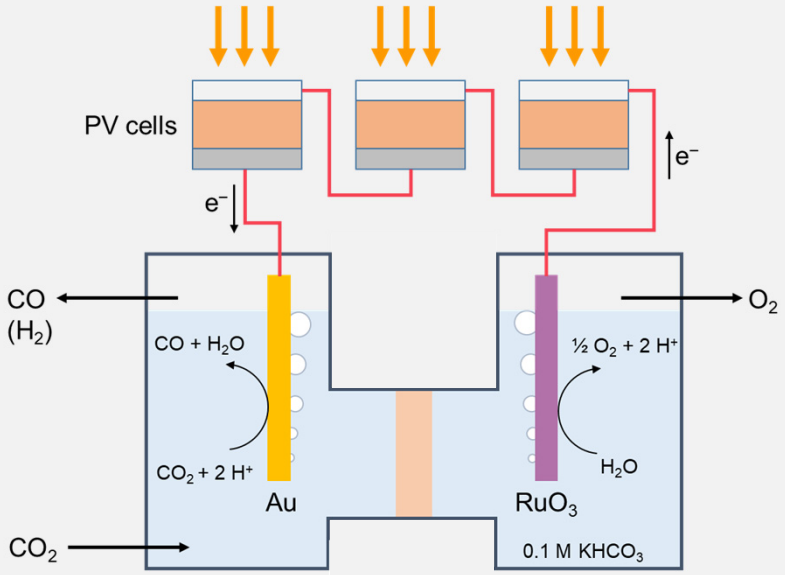
Hole transport layer
Bottom electrode
Substrate



	E_g (eV)	d (nm)	J_{sc} (mA cm^{-2})	V_{oc} (V)	FF	PCE (%)
$Cs_{0.1}(FA_{0.66}MA_{0.34})_{0.9}PbI_2Br$	1.73	400	17.3	1.13	0.74	14.5
$FA_{0.66}MA_{0.34}PbI_{2.85}Br_{0.15}$	1.57	450	22.9	1.09	0.78	19.5
$FA_{0.66}MA_{0.34}Pb_{0.5}Sn_{0.5}I_3$	1.23	430	28.0	0.78	0.73	15.9

Photo-electrochemical reduction of CO_2 to CO and H_2

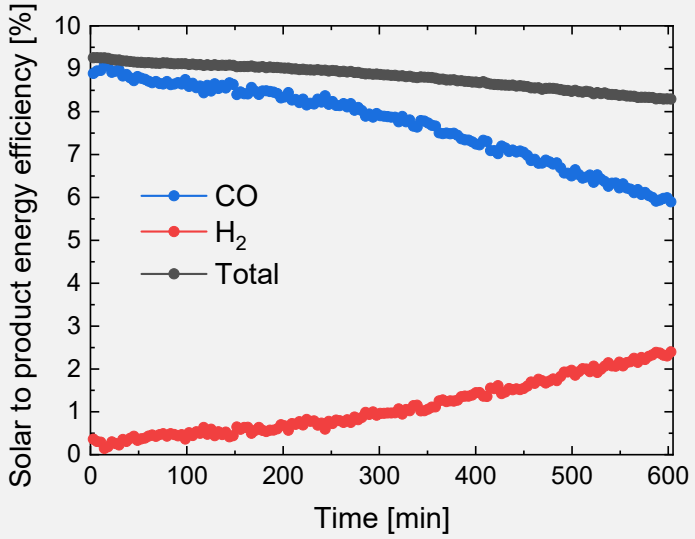
Solar-to-fuel energy efficiency: 8-9%



RuO_3 anode: $H_2O \rightarrow ½\ O_2 + 2\ H^+ + 2\ e^-$

Au cathode: $CO_2 + 2\ H^+ + 2\ e^- \rightarrow CO + H_2O$

$2\ H^+ + 2\ e^- \rightarrow H_2$



Serkan Esiner, Cell Reports Physical Science 2020, **1**, 100058

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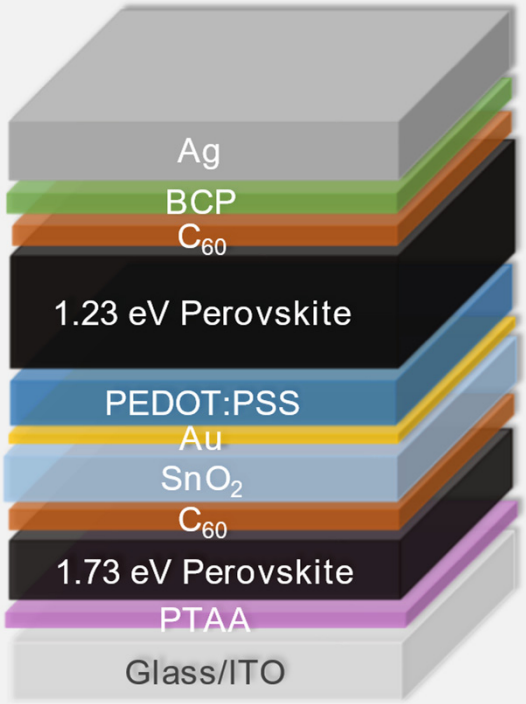
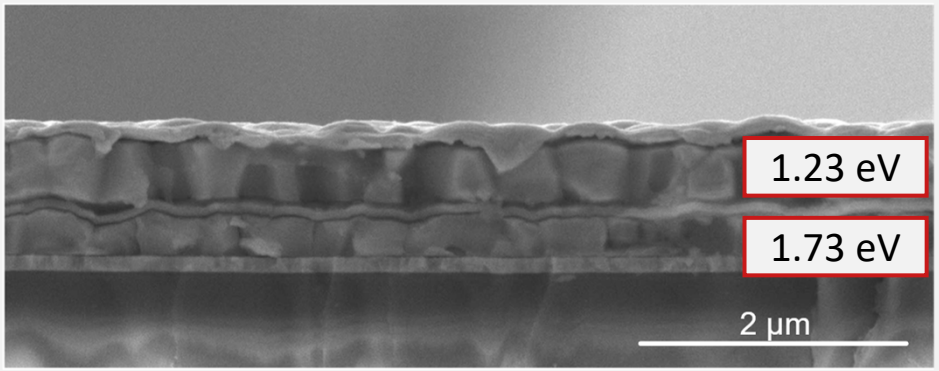
Tandem cells – 19.8%

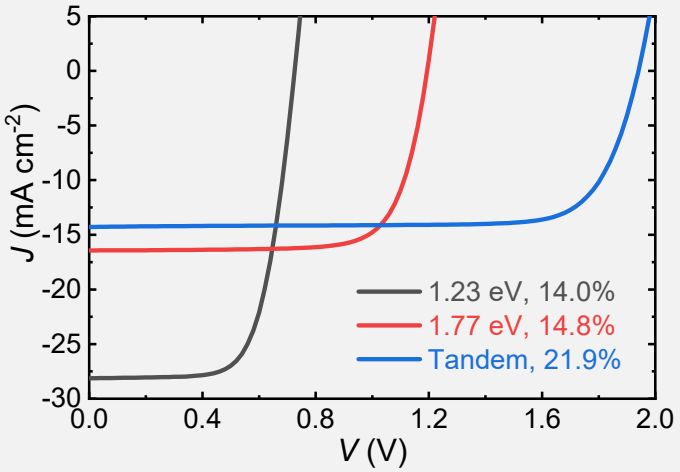


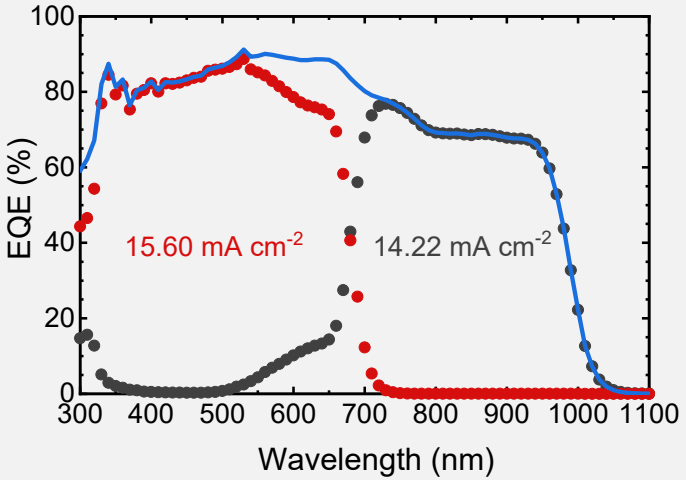
- 2 different band gap perovskites at **1.73** and **1.23** eV
- 11 functional layers integrated ~ 1 µm thick



Junke Wang, Nature Commun. **2020**, 11, 5254

Tandem cells – 21.9%



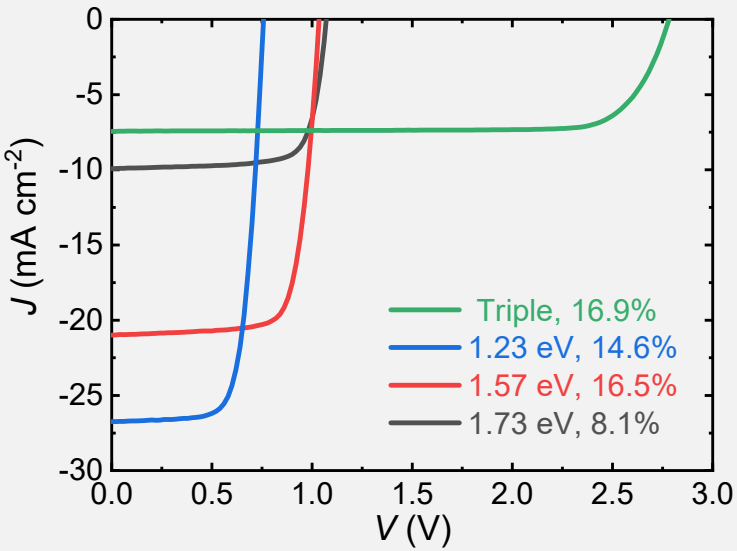


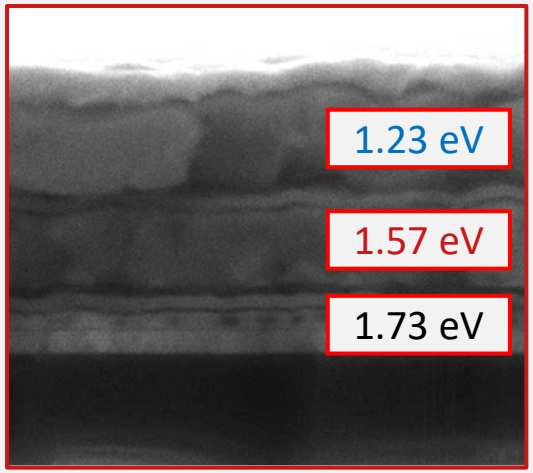
ITO	J_{sc} (mA cm^{-2})	V_{oc} (V)	FF	PCE (%)
1.23 eV	28.1	0.73	0.69	14.0
1.73 eV	16.4	1.19	0.75	14.8
Tandem	14.3	1.94	0.79	21.9

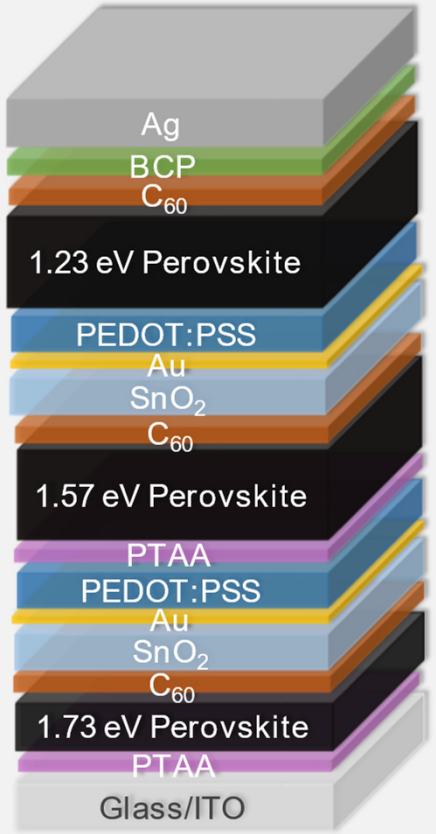
Junke Wang, Kunal Datta, Valerio Zardetto, et al. (to be published)

Triple cells - 16.8%

- 3 different band gap perovskites at **1.73**, **1.57** and **1.23** eV working in concert
- 17 functional layers integrated in a single device < 1.5 µm thick







Junke Wang, Nature Commun. **2020**, 11, 5254

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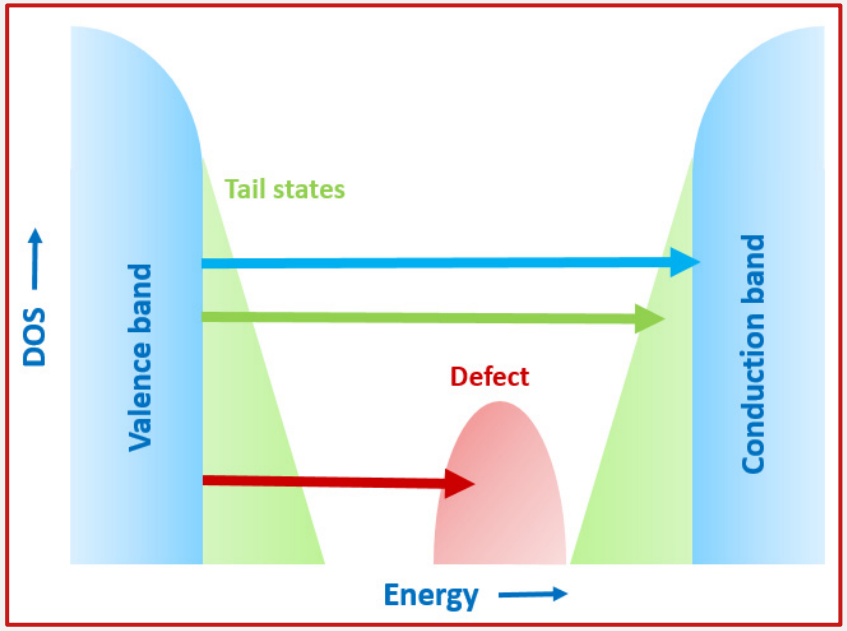
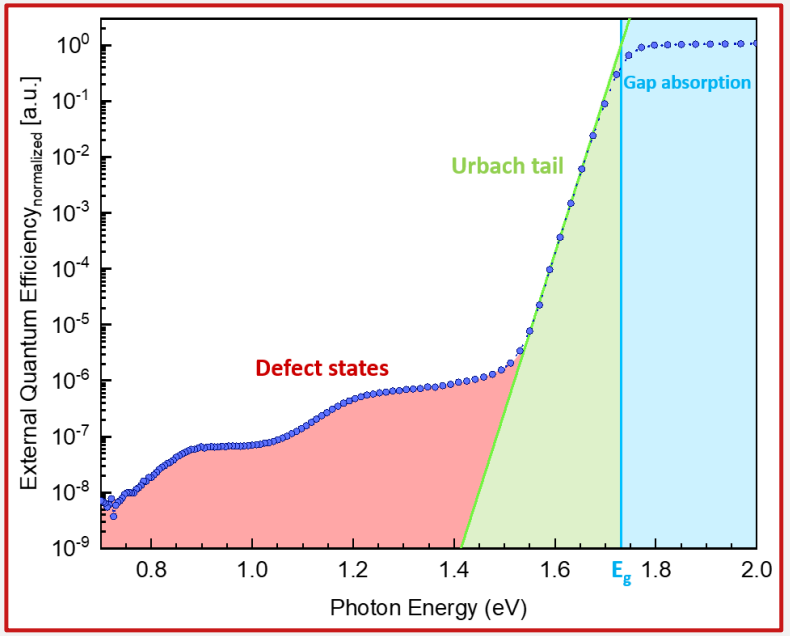
Ultrasensitive sub band gap photocurrent spectroscopy





- Nine orders of magnitude in EQE
- Allows determining energy & location of defect

Bas van Gorkom, to be submitted

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Acknowledgements

Members and former members of M2N group

National & International collaborations
Funding

תודה על תשומת לבכם.
Thank you for your attention
Dank voor uw aandacht