Efficient polymer solar cells and first step beyond that

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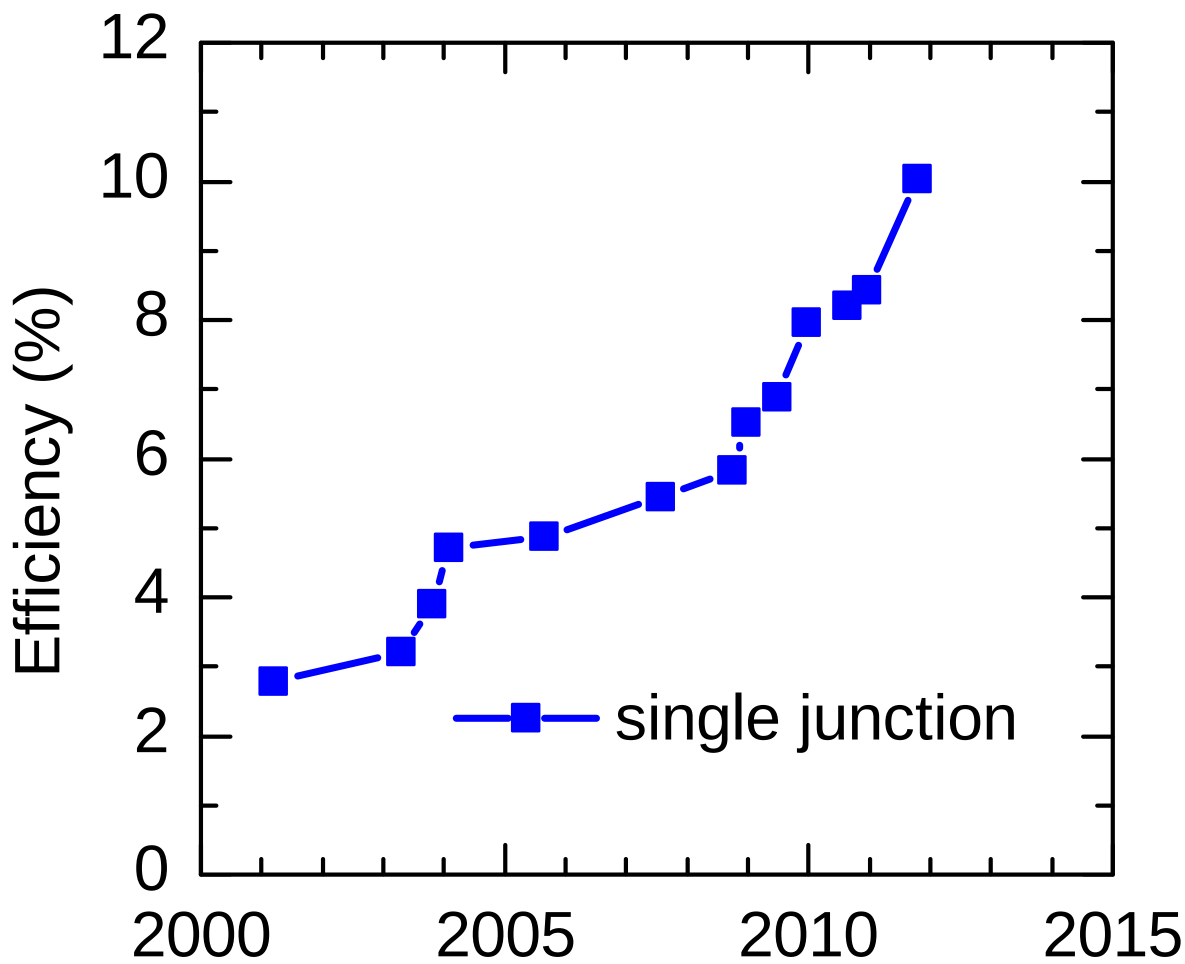
EASAC workshop
Renewables – systems and storage
Stockholm, 19-20 September, 2013

Technische Universiteit
Eindhoven
University of Technology

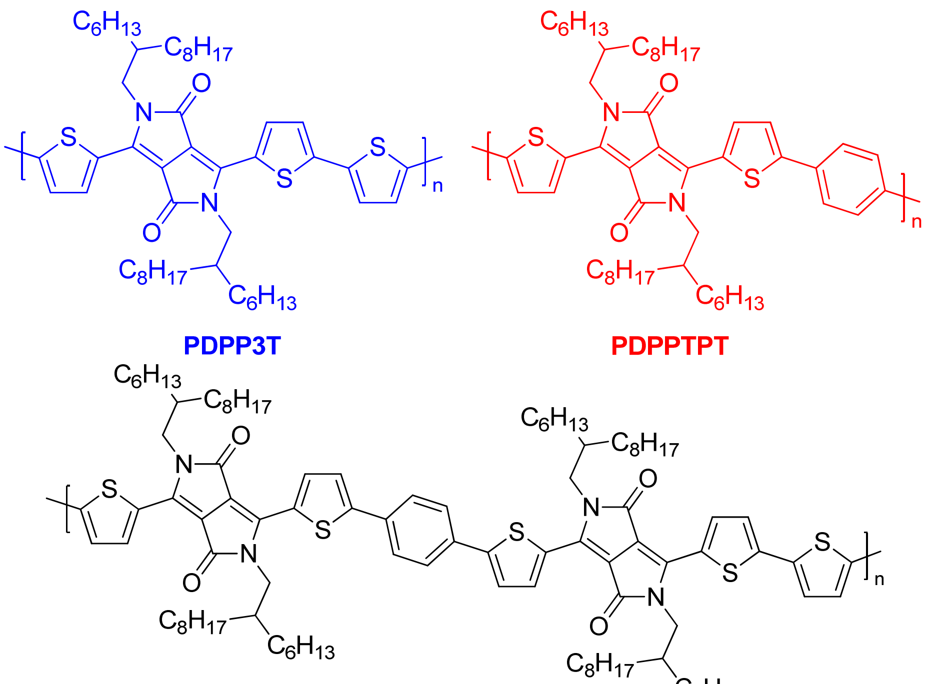
Where innovation starts

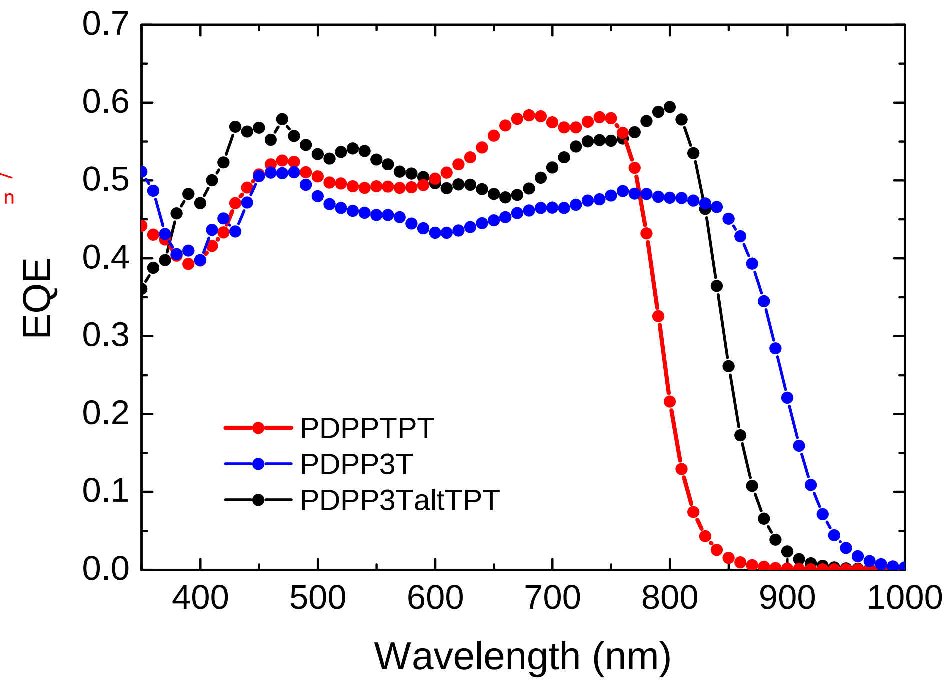
OPV efficiencies are increasing rapidly



All new materials

Recent efficient DPP type polymers

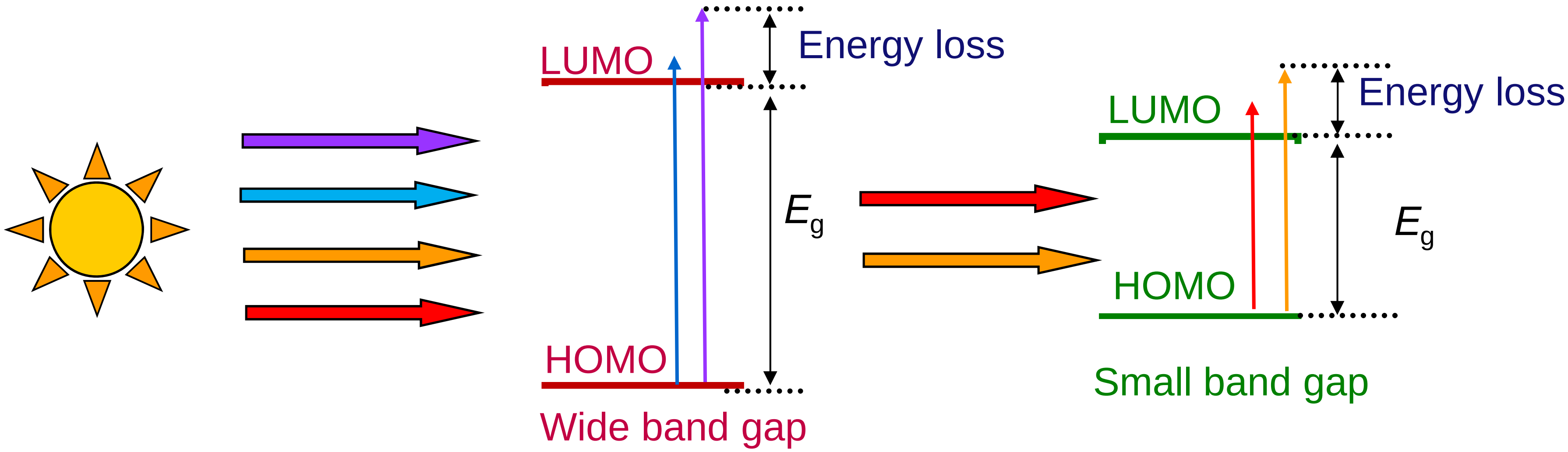




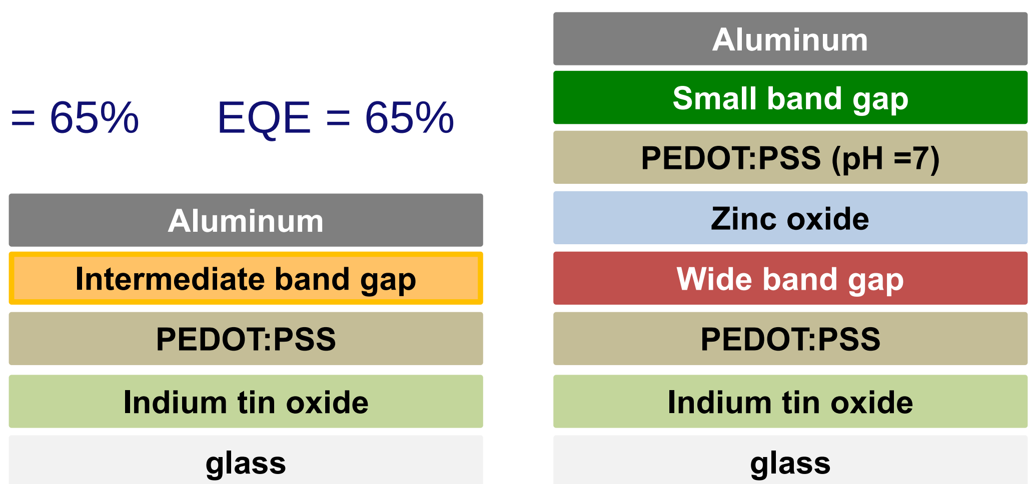
Polymer	E_g (eV)	J_{sc} (mA/cm^2)	V_{oc} (V)	FF	EQE_{max}	PCE (%)
PDPP3T*alt*TPT	1.44	15.9	0.74	0.67	0.59	8.0
PDPPTPT	1.50	14.0	0.80	0.67	0.58	7.4
PDPP3T	1.33	15.4	0.67	0.69	0.49	7.1

Koen Hendriks, Angew. Chem. Int. Ed. ***2013****, 52, 8341–8344.*

Preserving photon energy in tandem cells



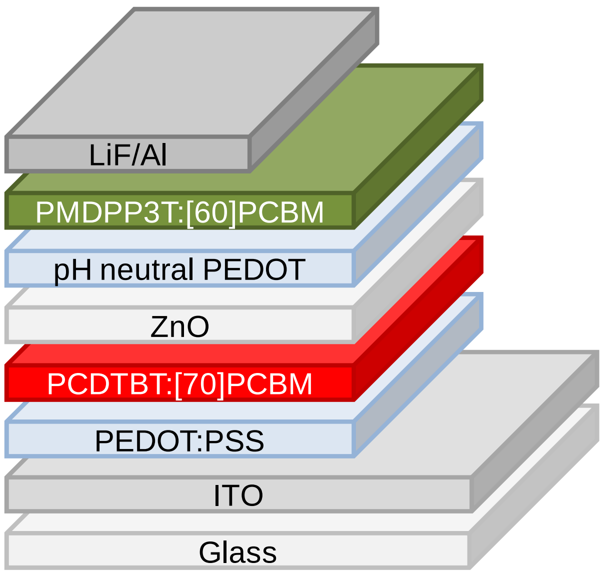
Assuming
$V_{oc} = E_g$ - 0.6 V FF = 65% EQE = 65%



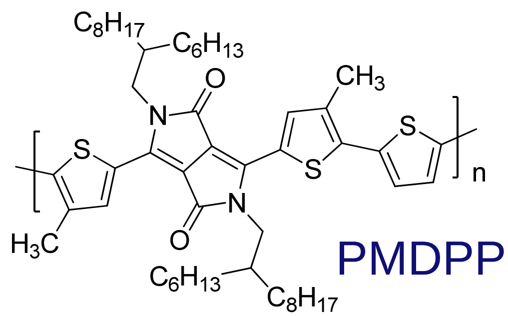
11.0% → **15.0%**

Harm van Eersel

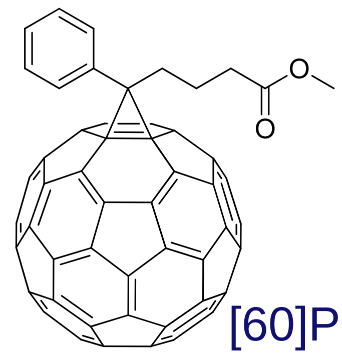
Tandem polymer solar cells



E_g = 1.3 eV; PCE = 5.8%

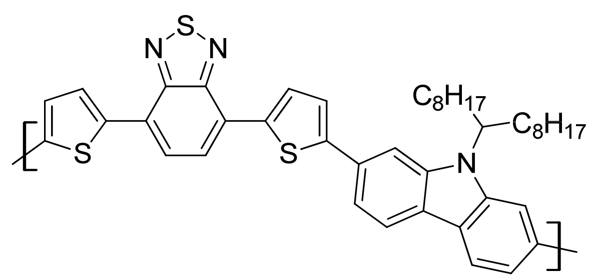


PMDPP3T

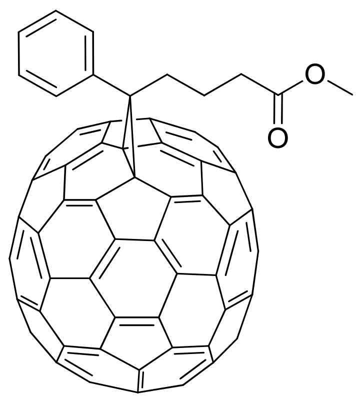


[60]PCBM

E_g = 1.9 eV; PCE = 5.8%



PCDTBT

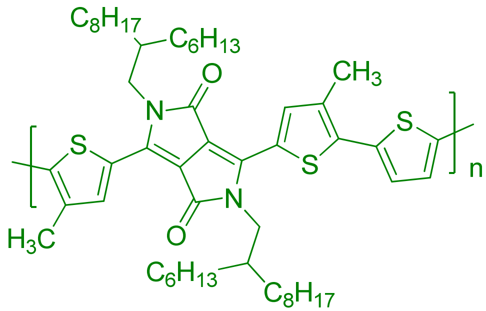


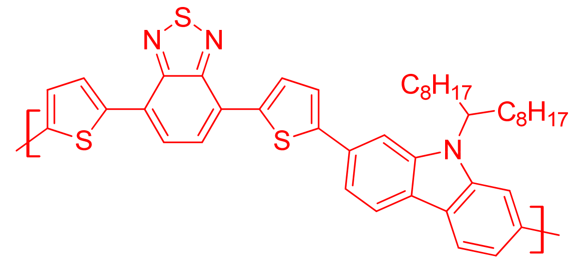
[70]PCBM

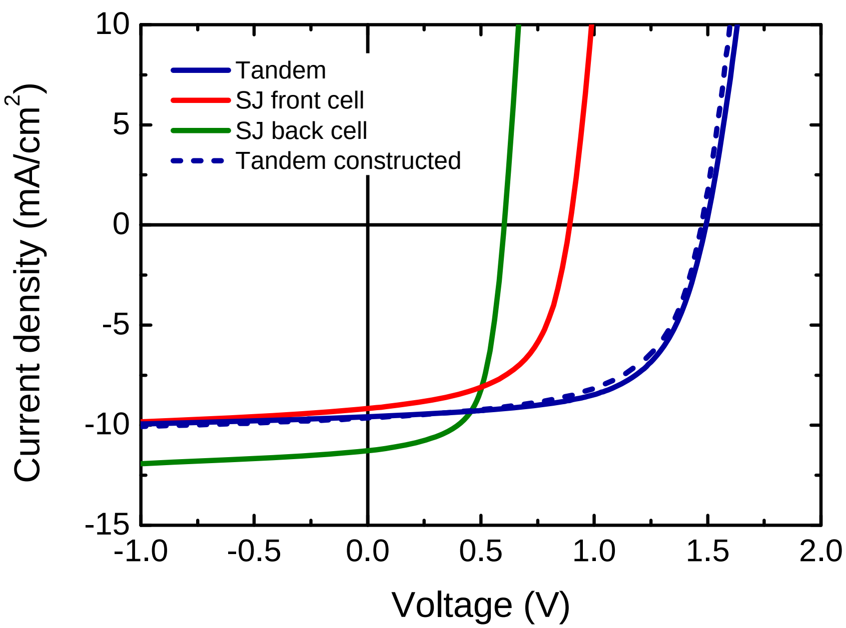
Weiwei Li & Alice Furlan

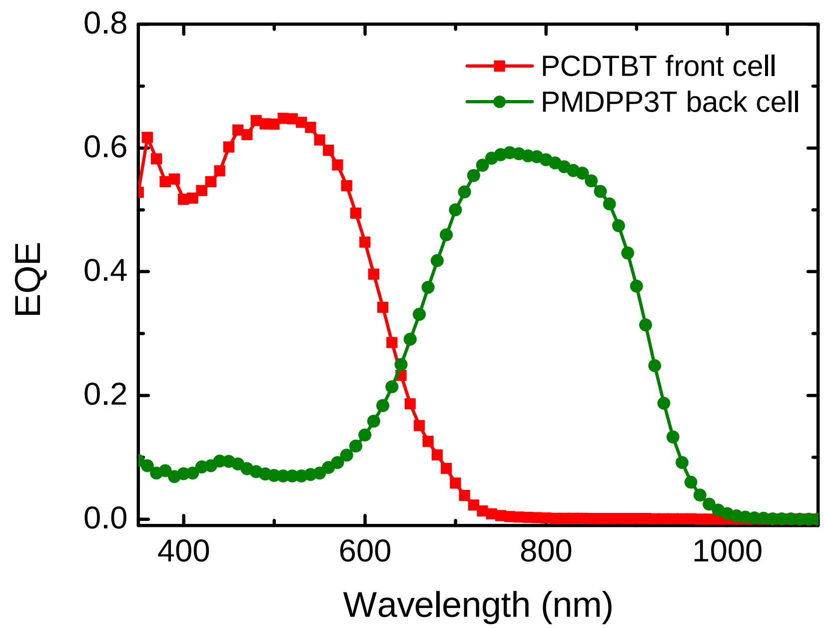
Tandem cell performance 8.9%

J_{sc} (mA/cm²)	V_{oc} (V)	FF (-)	PCE (%)
9.56	1.46	0.62	8.90







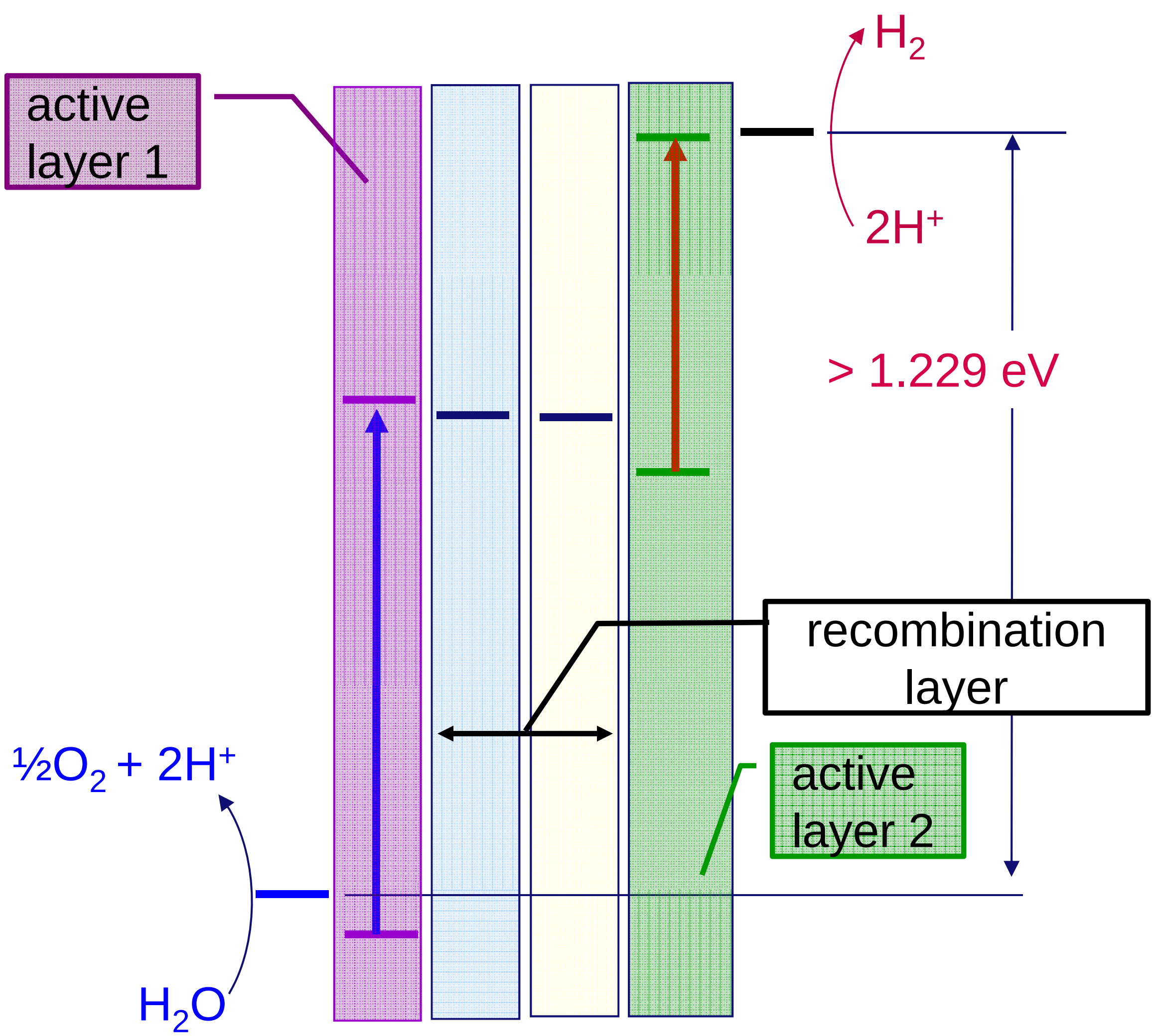


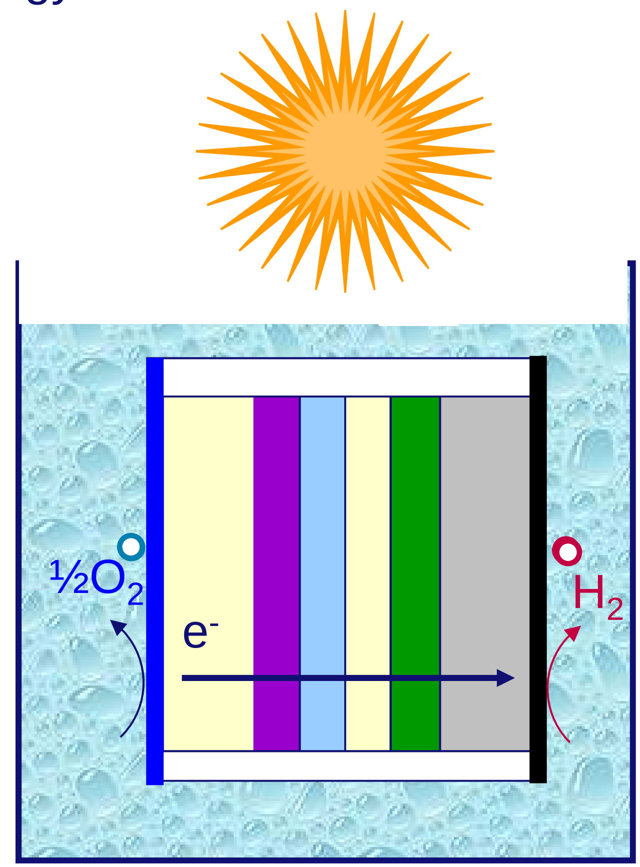
Weiwei Li & Alice Furlan

J. Am. Chem. Soc. ***2013***, 135, 5529–5532.

Tandem cells for an organic artificial leaf

Organic tandem configurations convert light into the required chemical potential using two active layers and two photons of different energy



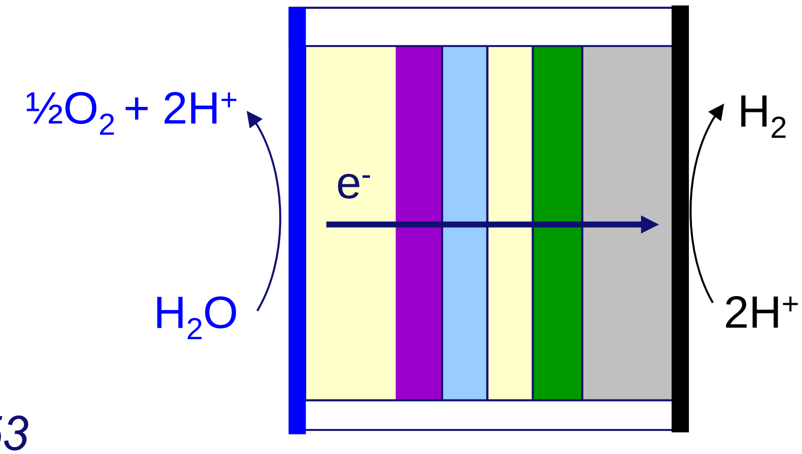


Electrolysis

E^{0}_{H2O} = 1.229 eV

overpotential losses, ς

$V_{H2O} = E^{0}_{H2O} + \varsigma_{O2} - \varsigma_{H2}$



S. Licht, J. Hydrogen Energy ***2001****, 26, 653*

Platinum black as H_2 electrocatalyst

RuO_2 as O_2 electrocatalyst

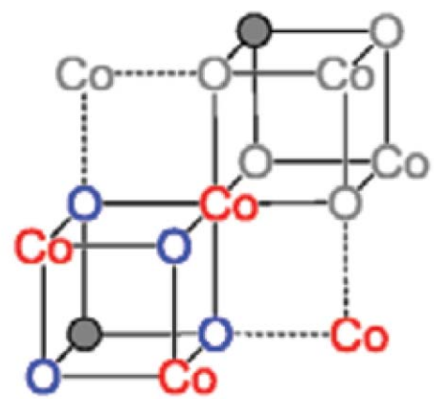
V_{H2O} = 1.36 V with electrolysis efficiencies up to 90%

D.G. Nocera, Acc. Chem. Res. ***2012****, 45, 667*

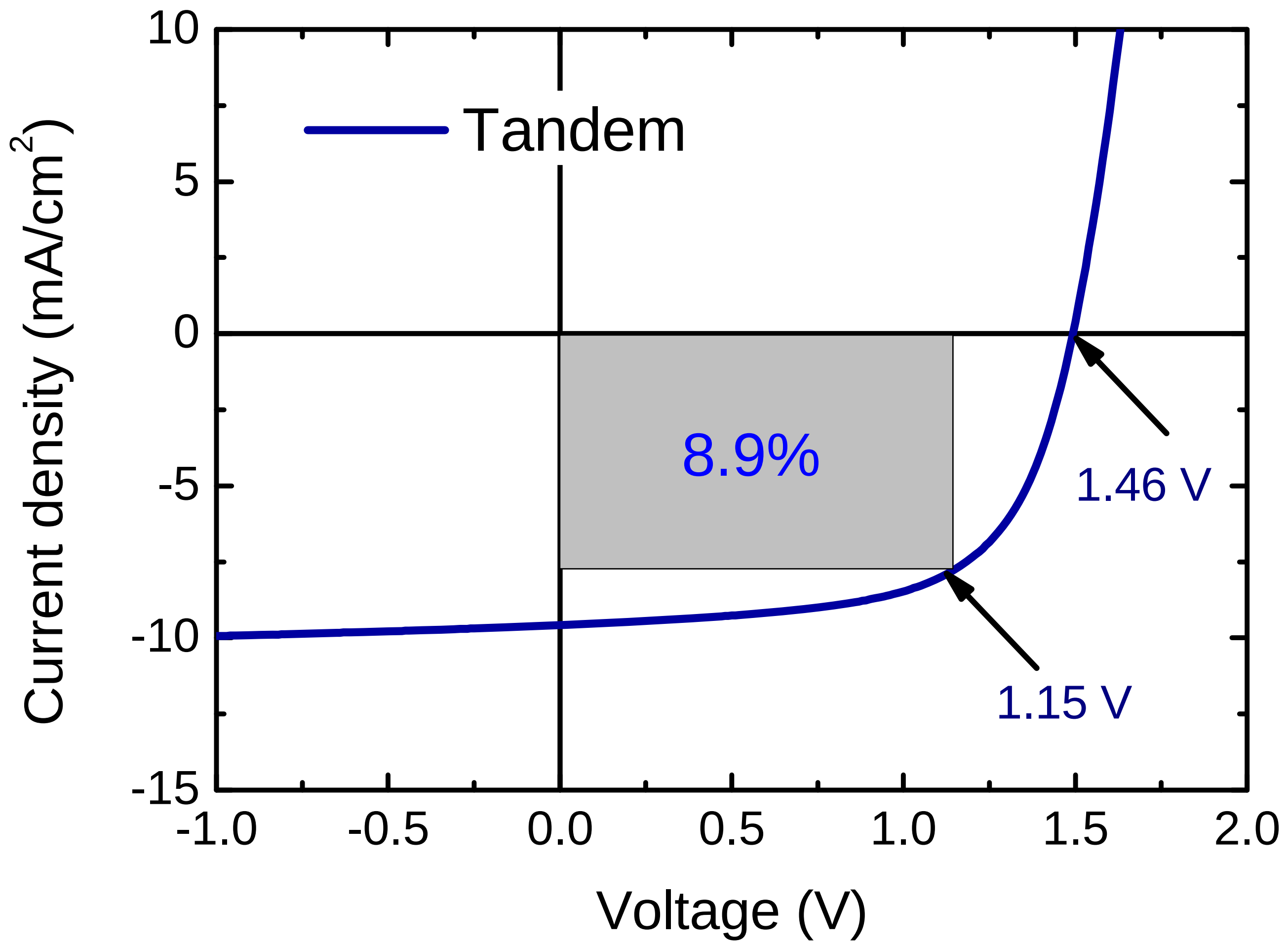
NiMoZn black as H_2 electrocatalyst

CoO cubane as O_2 electrocatalyst

ς = 0.10-0.35 V (700-1000 mA/cm^2)

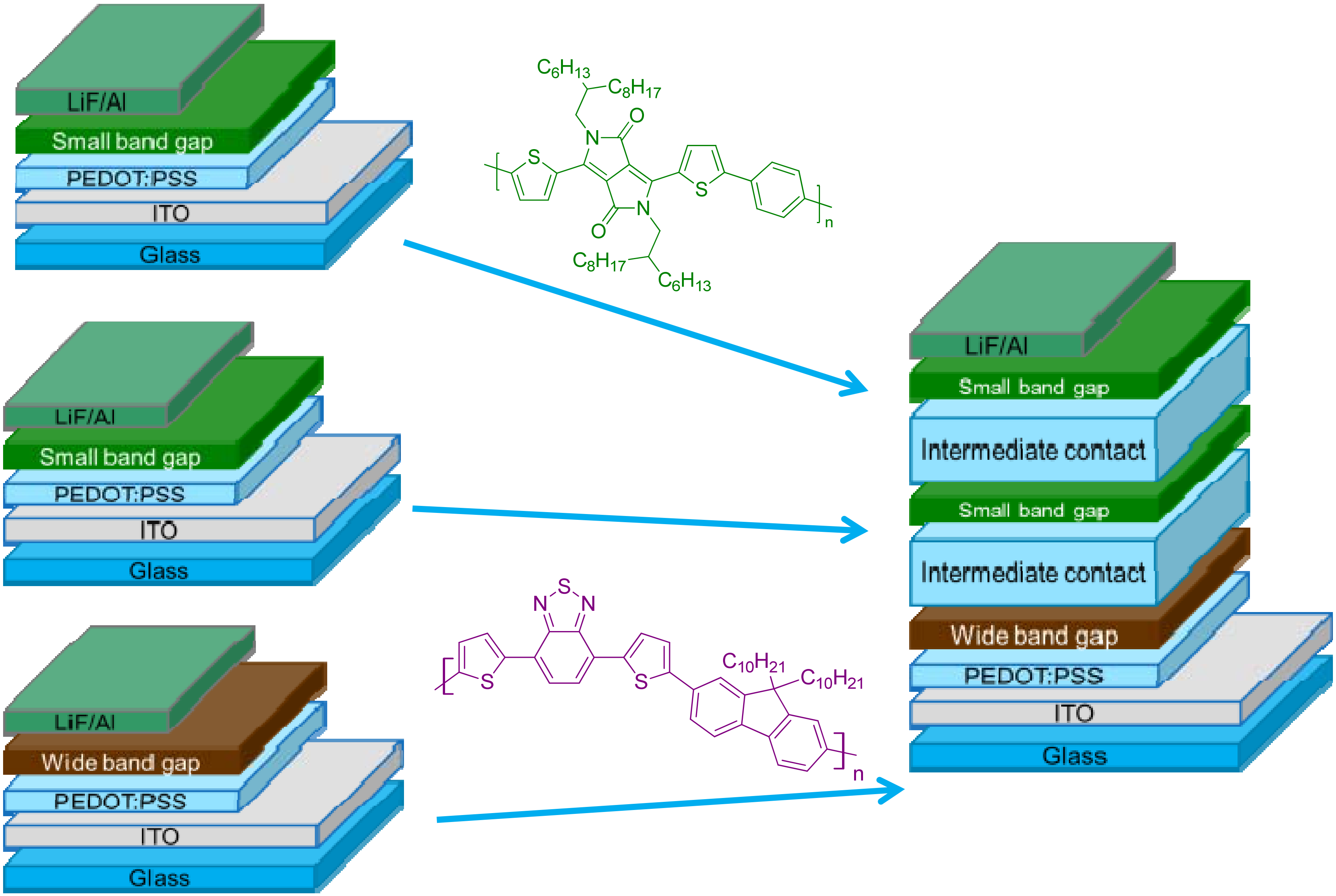


Did we accomplished what is required?

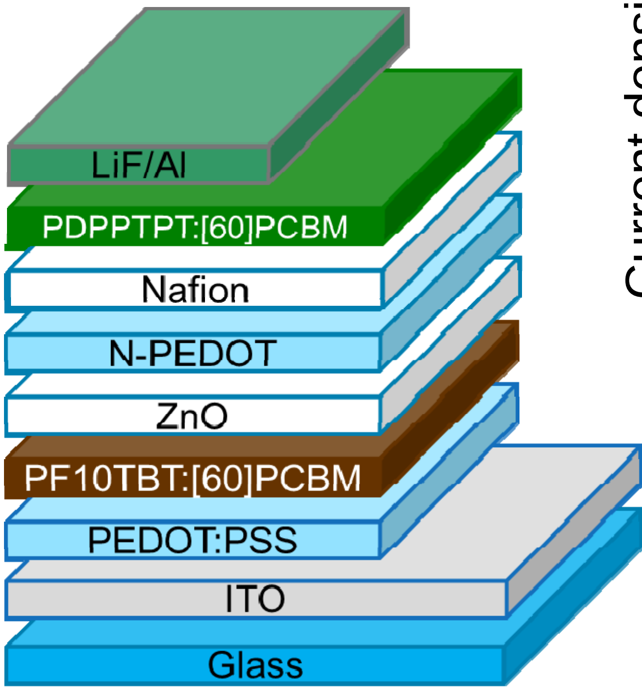


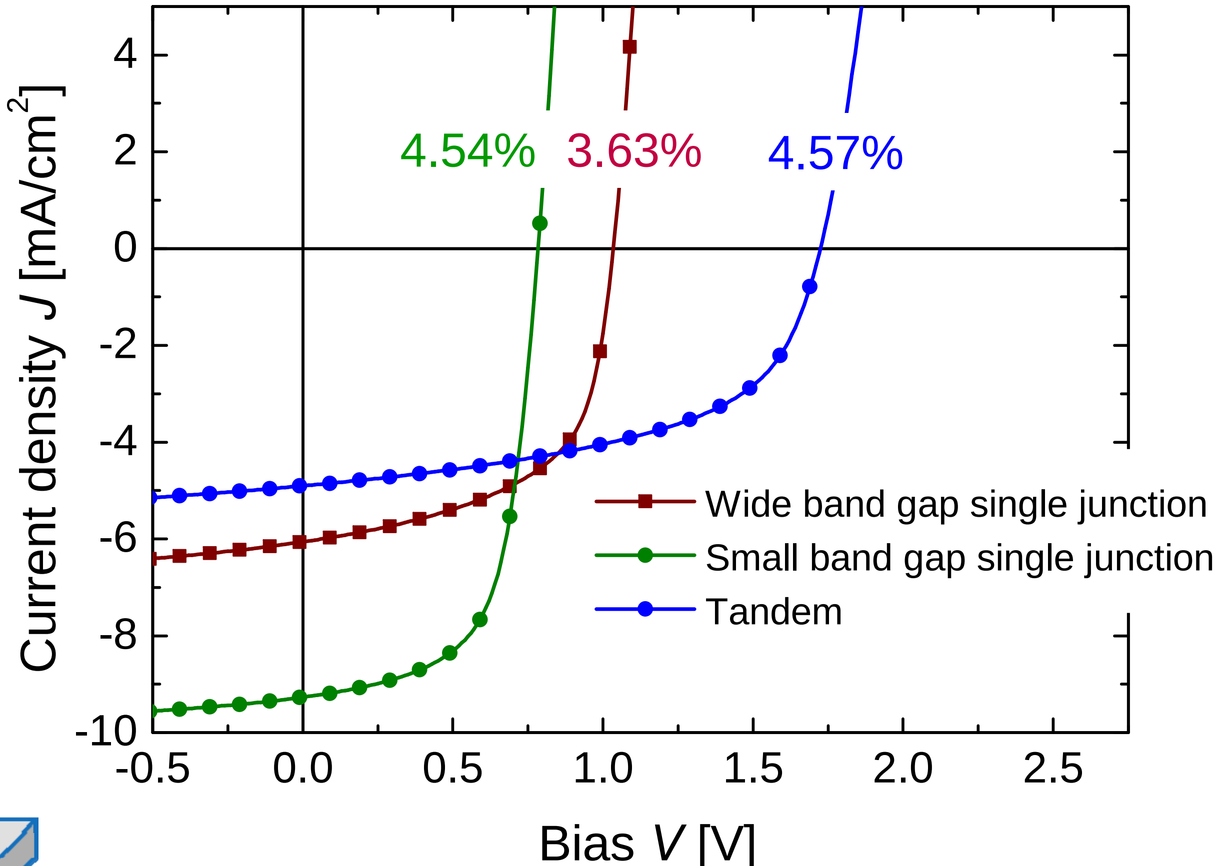
Maybe not! What can we do about it?

Triple junctions – a first attempt 2 +1



Tandem junction made: 4.6%

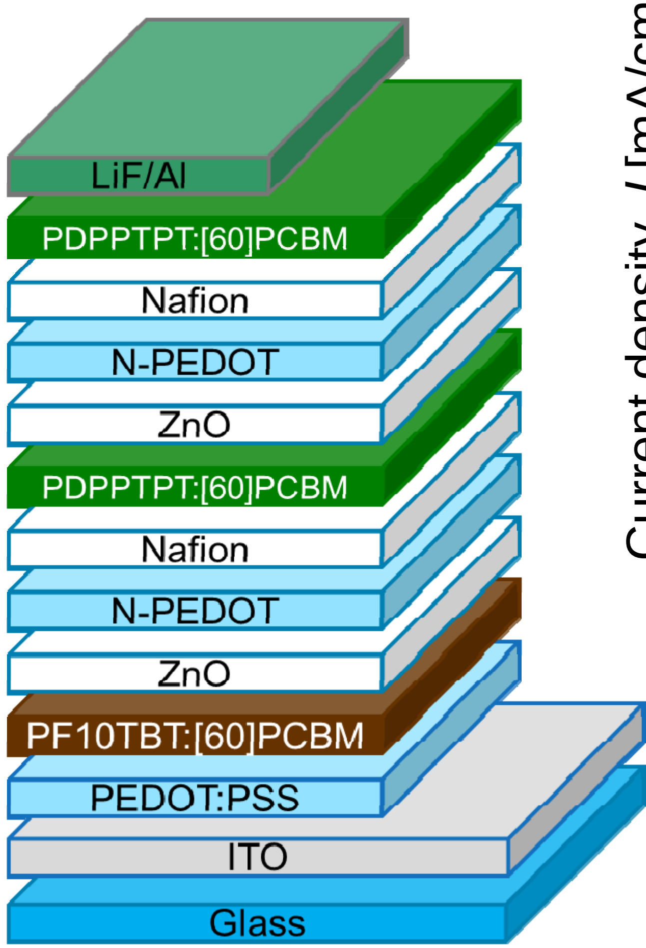


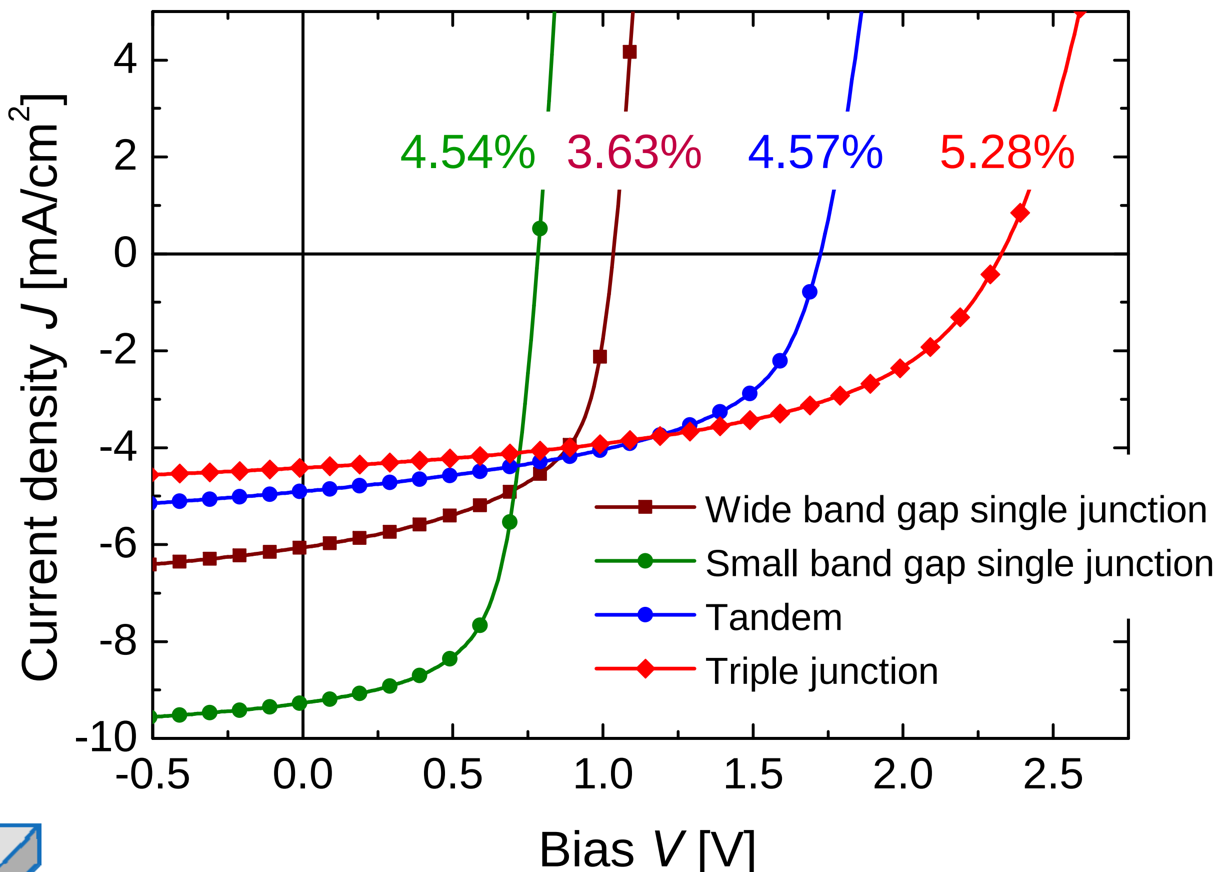


6 solution processed layers

Serkan Esiner, Adv. Mater ***2013****, 25, 2932–2936.*

Triple junction made: 5.3%

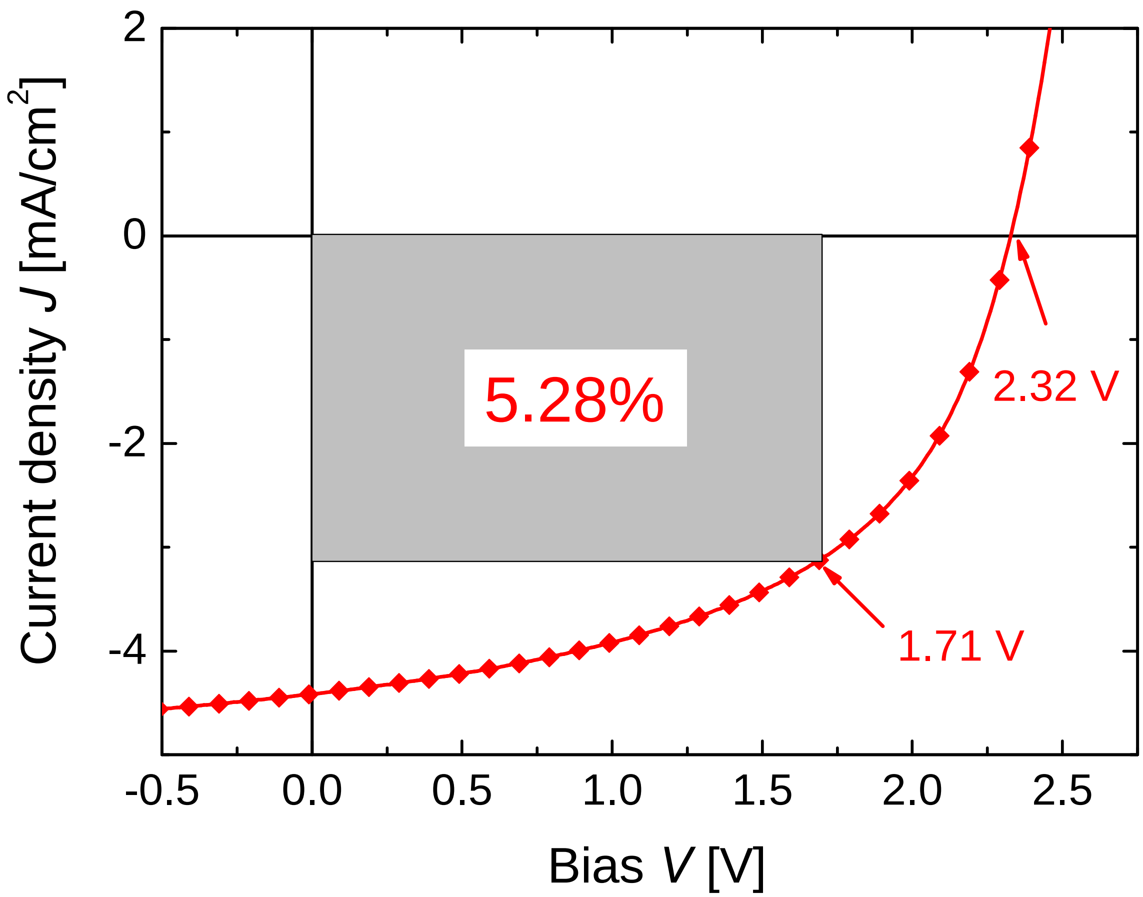




10 solution processed layers

Serkan Esiner, Adv. Mater ***2013****, 25, 2932–2936.*

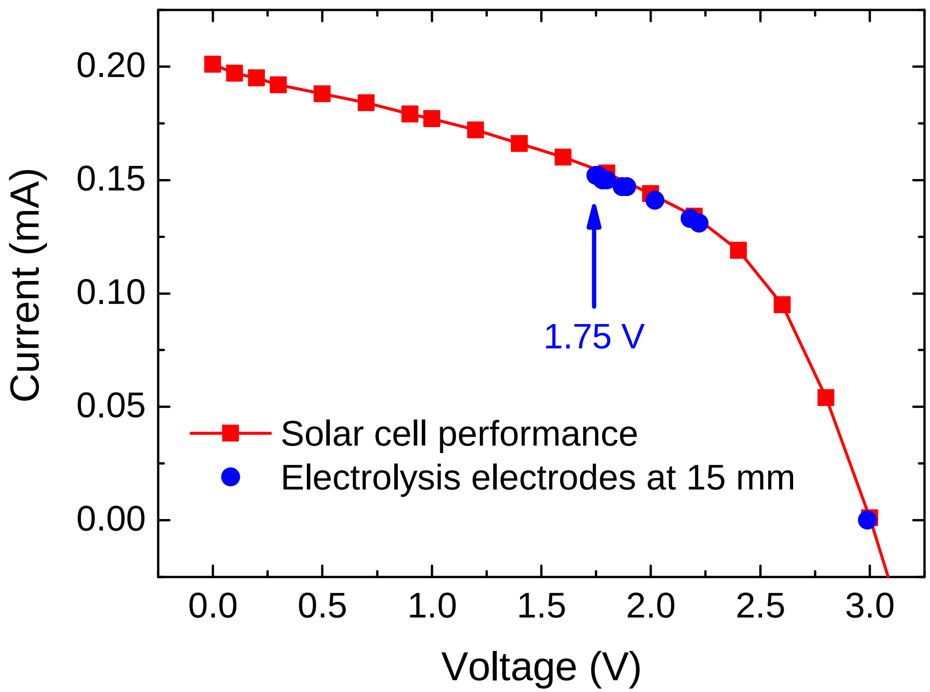
Now we seem in business!



Serkan Esiner

Electrolysis vs. solar cell

Measured by dipping the two electrodes further into the solution

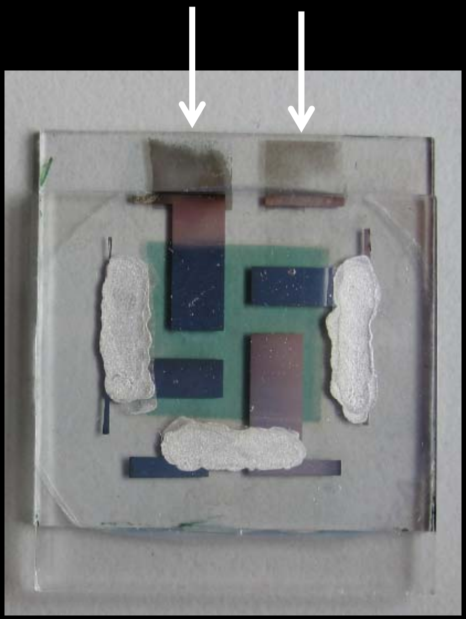


Faradaic (quantum) efficiency 100% (upper limit)
Energy efficiency 1.24/1.75 = 71%
Solar to H_2 energy conversion efficiency = 3.75% (upper limit)

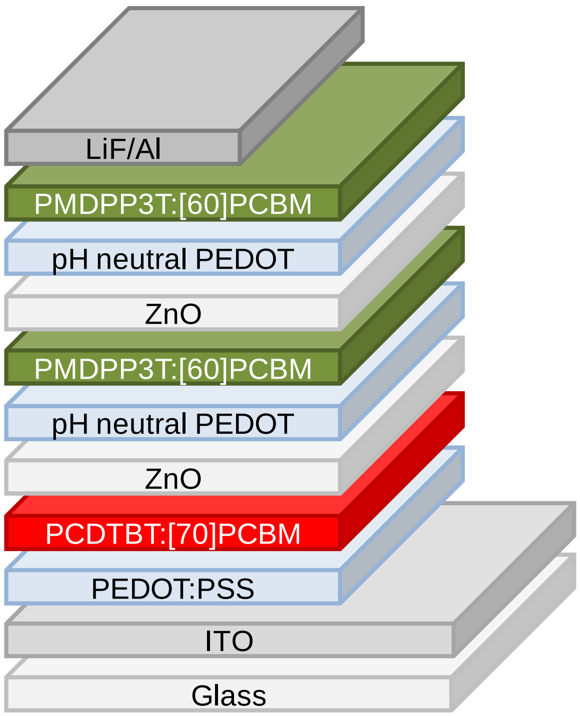
Serkan Esiner

Swimming OPV cells producing H_2

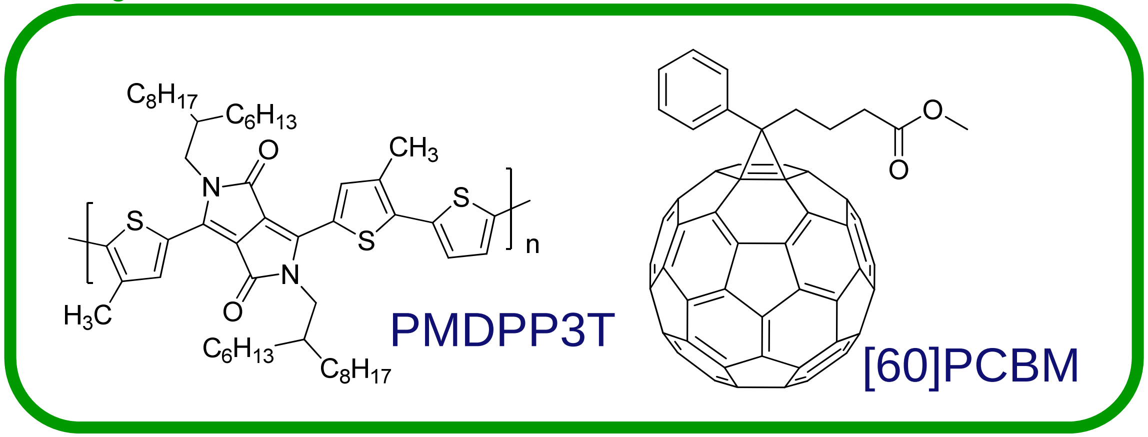
HER and OER catalysts



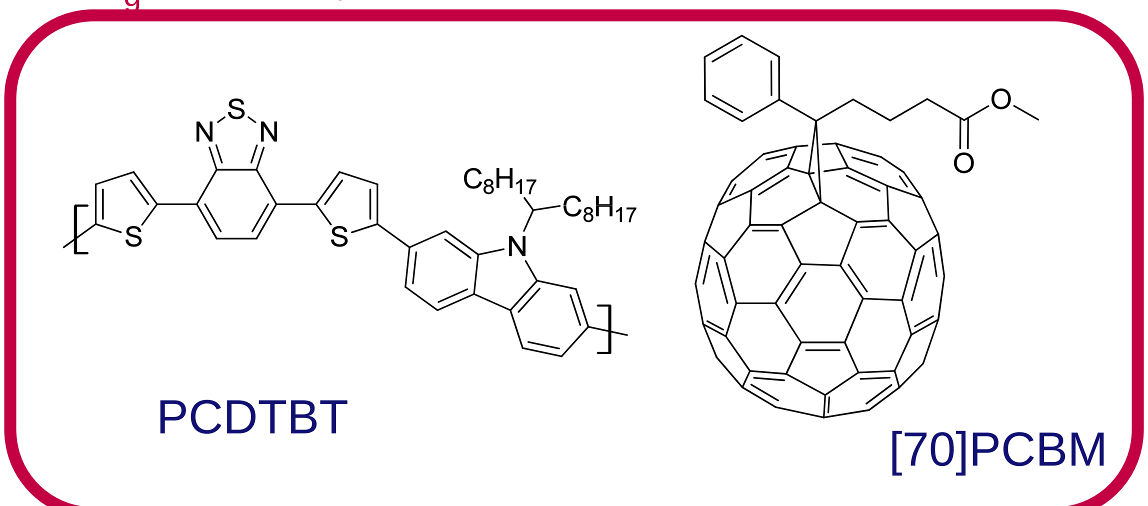
Improved 1+2 triples



E_g = 1.3 eV; PCE = 5.8%



E_g = 1.9 eV; PCE = 5.8%



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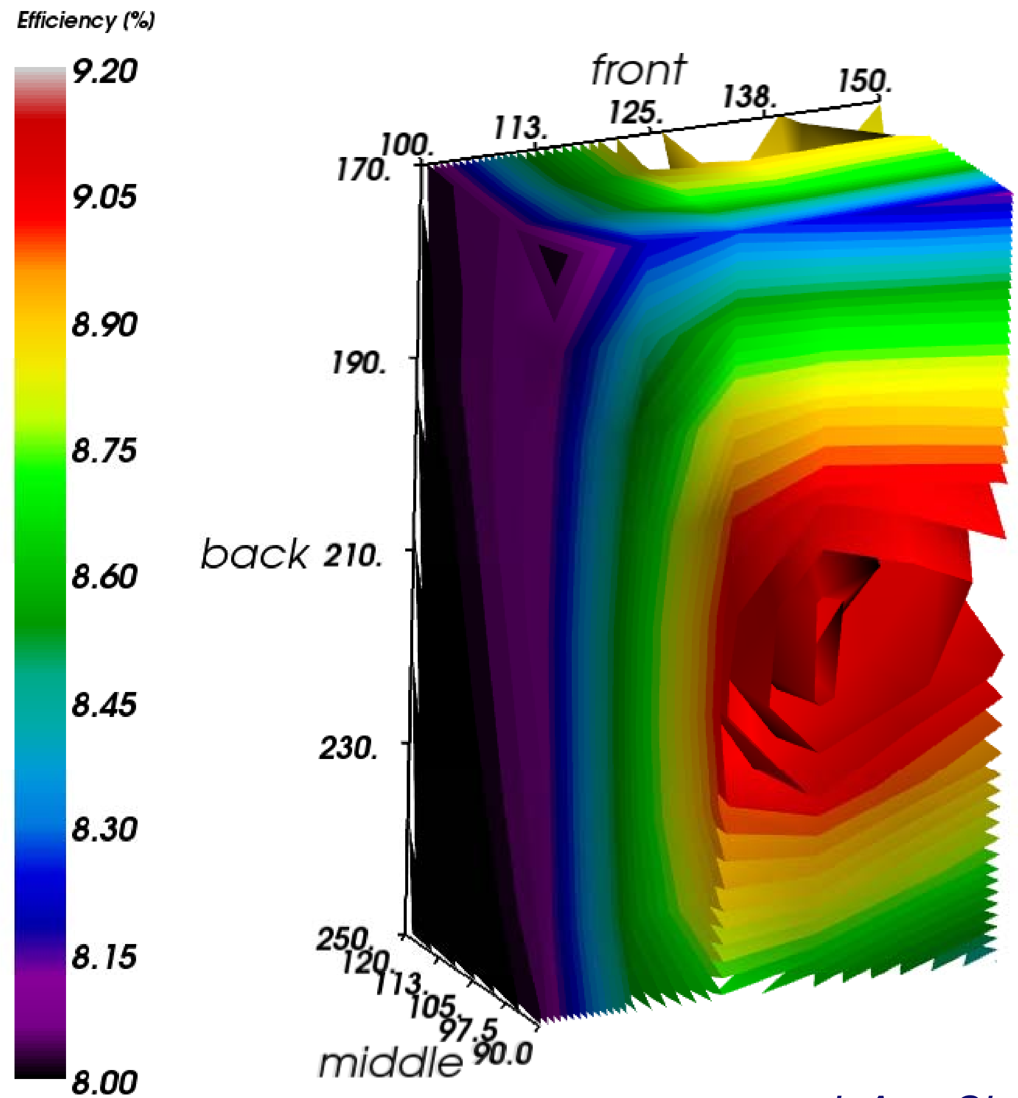
Optimization of 1+2 triple junction



Maximum efficiency expected for

Front 125 nm
Middle , 95 nm
Back 215 nm

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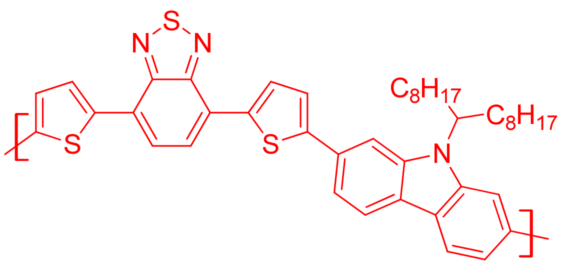
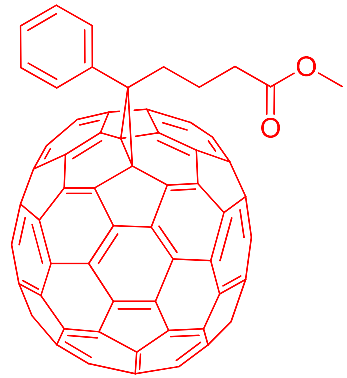
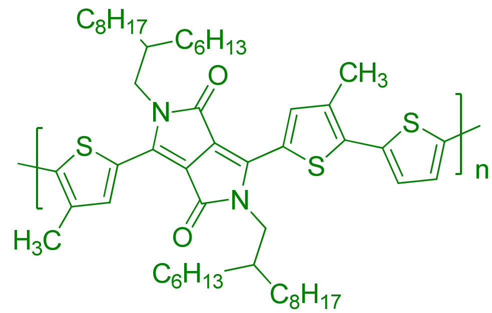
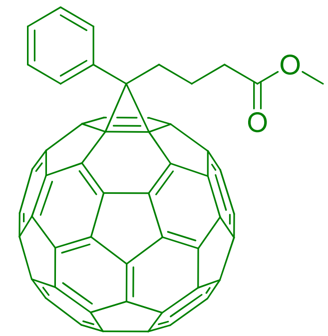
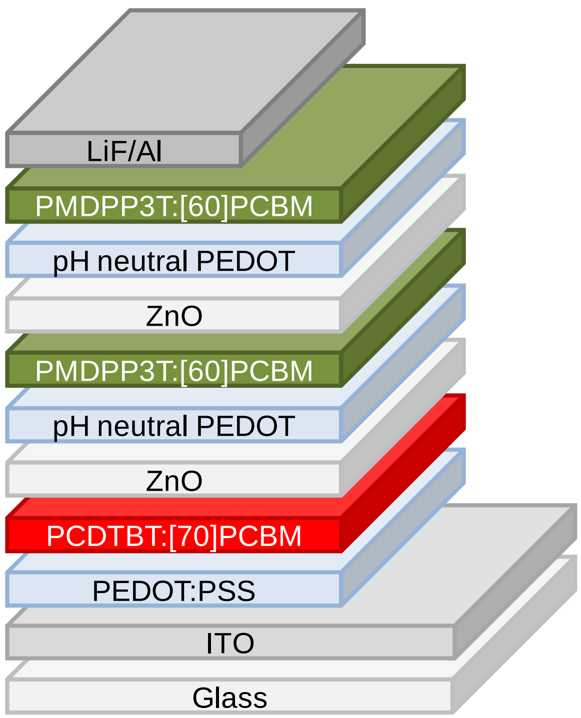
Triple junctions : 1+2

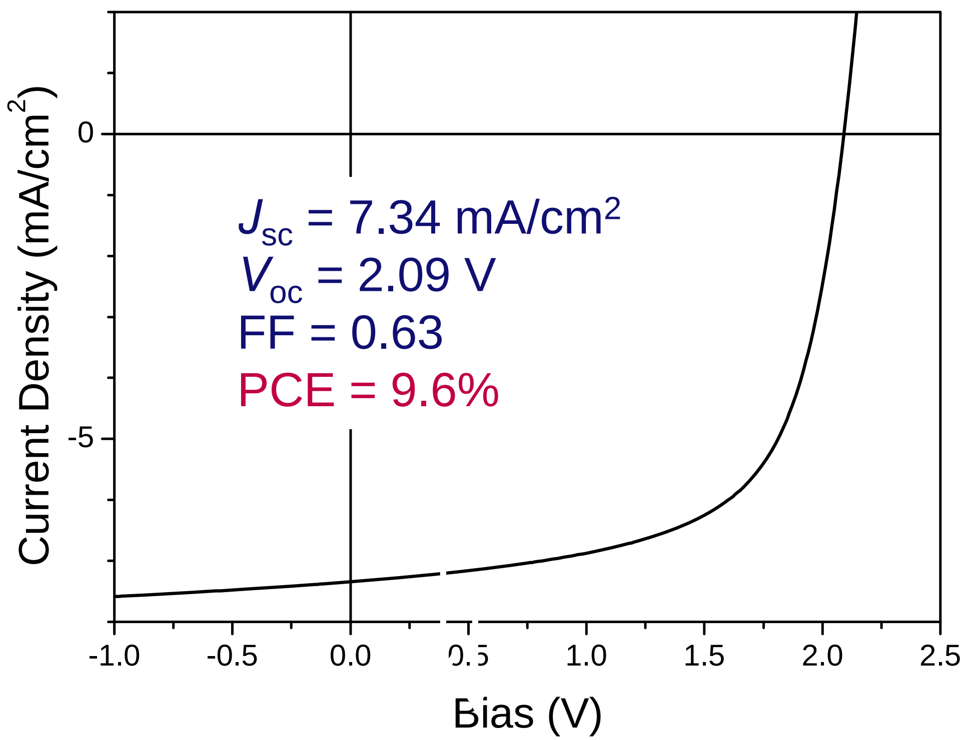












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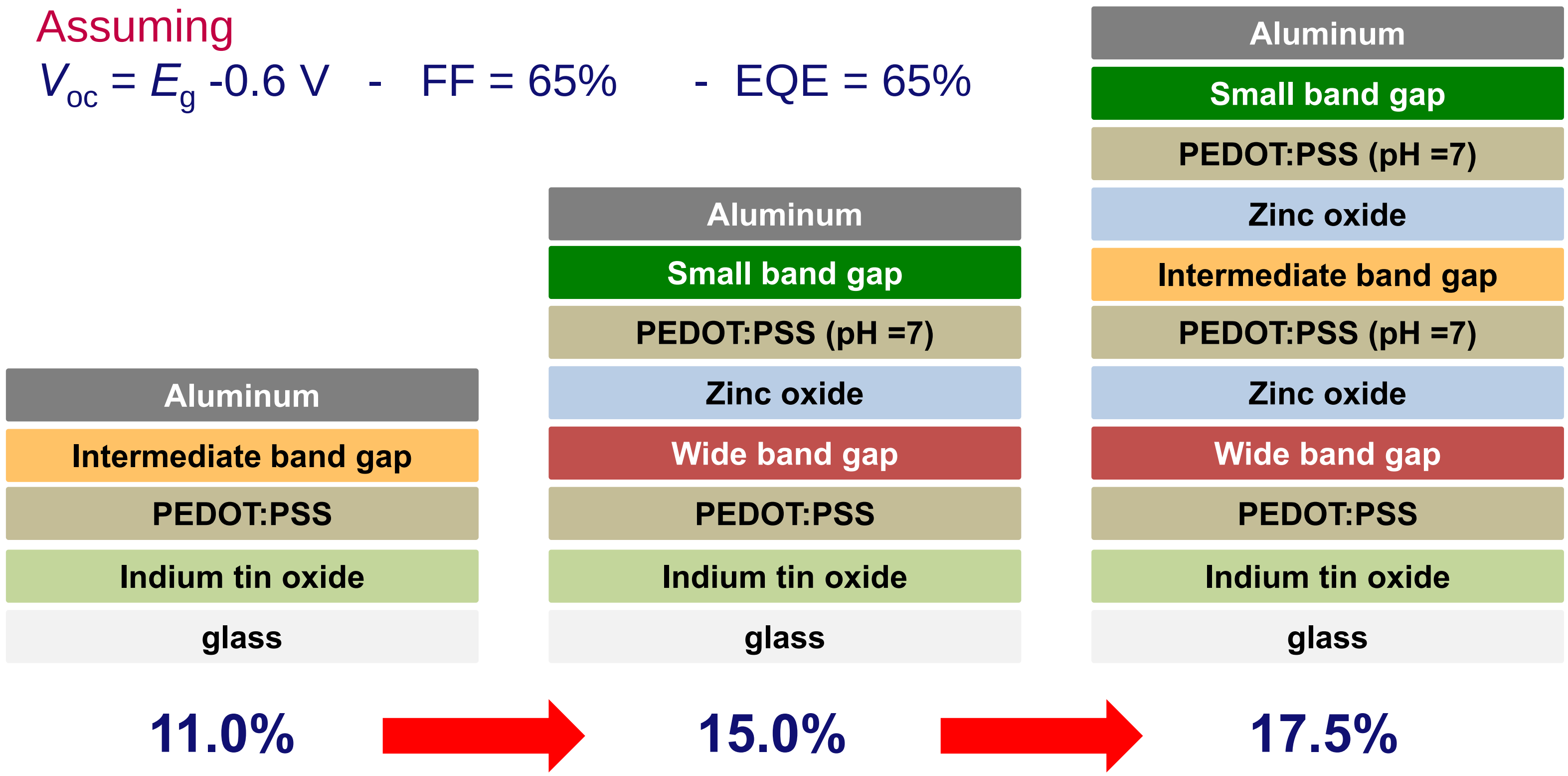
Single, double, triple: max efficiencies

Assuming
$V_{oc} = E_g$ -0.6 V - FF = 65% - EQE = 65%



$\eta_{photoelectrolysis} = \eta_{photo} \times \eta_{electrolysis}$

Solar light to hydrogen energy efficiency:

Estimated realistic target: ~17.5% × 90% = 15.8%

Harm van Eersel

Summary - Future

***η*-photo**

Single junction cells made with 8.0% PCE
Tandem cells made with 8.9% PCE
Triple junctions made with 9.6% PCE
Triple junction cells have the required potential for water splitting at the maximum power point

***η*-electrolysis**

Works with an organic solar cell as power source

***η*-photoelectrolyis**

Demonstrated photoelectrochemical water splitting in an organic artificial leaf

Increase OPV efficiency to > 15%
Reduce overpotential losses for both half reactions with cheap materials

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NanoNextNL
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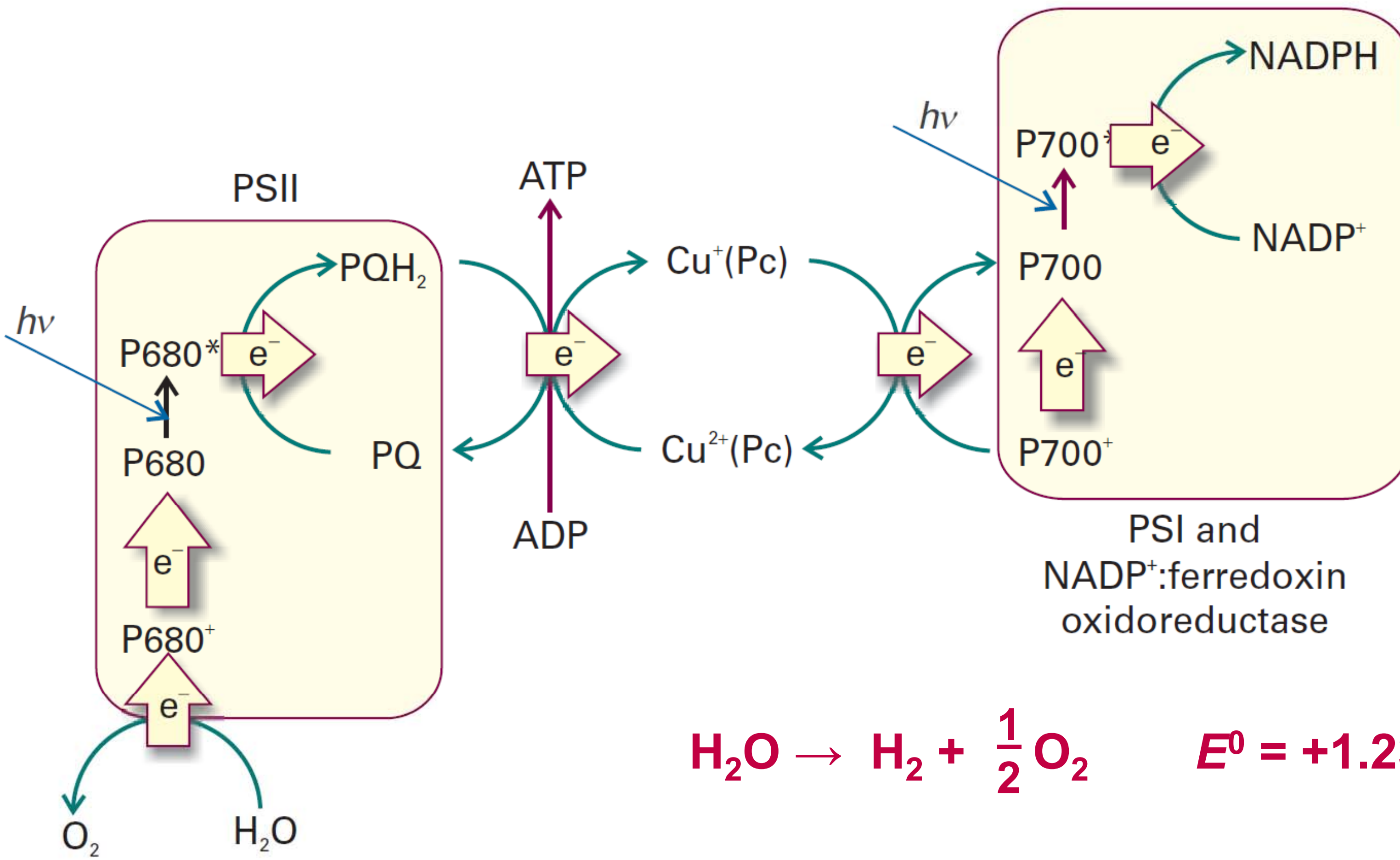
Largecells
X10D

SOLAR RESEARCH
SOLLIANCE

Storing energy in photosynthesis

$$CO_2 + H_2O \rightarrow \frac{1}{6} C_6H_{12}O_6 + O_2 \qquad E^0 = +1.24\ V$$

$$NADP^+ + H_2O \rightarrow NADPH + \frac{1}{2} O_2 + H^+ \qquad E^0 = +1.14\ V$$



$$H_2O \rightarrow H_2 + \frac{1}{2} O_2 \qquad E^0 = +1.23\ V$$