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Advanced optoelectronic tools to interrogate solution-processed solar cells

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specific®

EPSRC
Engineering and Physical Sciences Research Council

Swansea University
Prifysgol Abertawe

Imperial College London

The Centre for Plastic Electronics

Jenny Nelson's group

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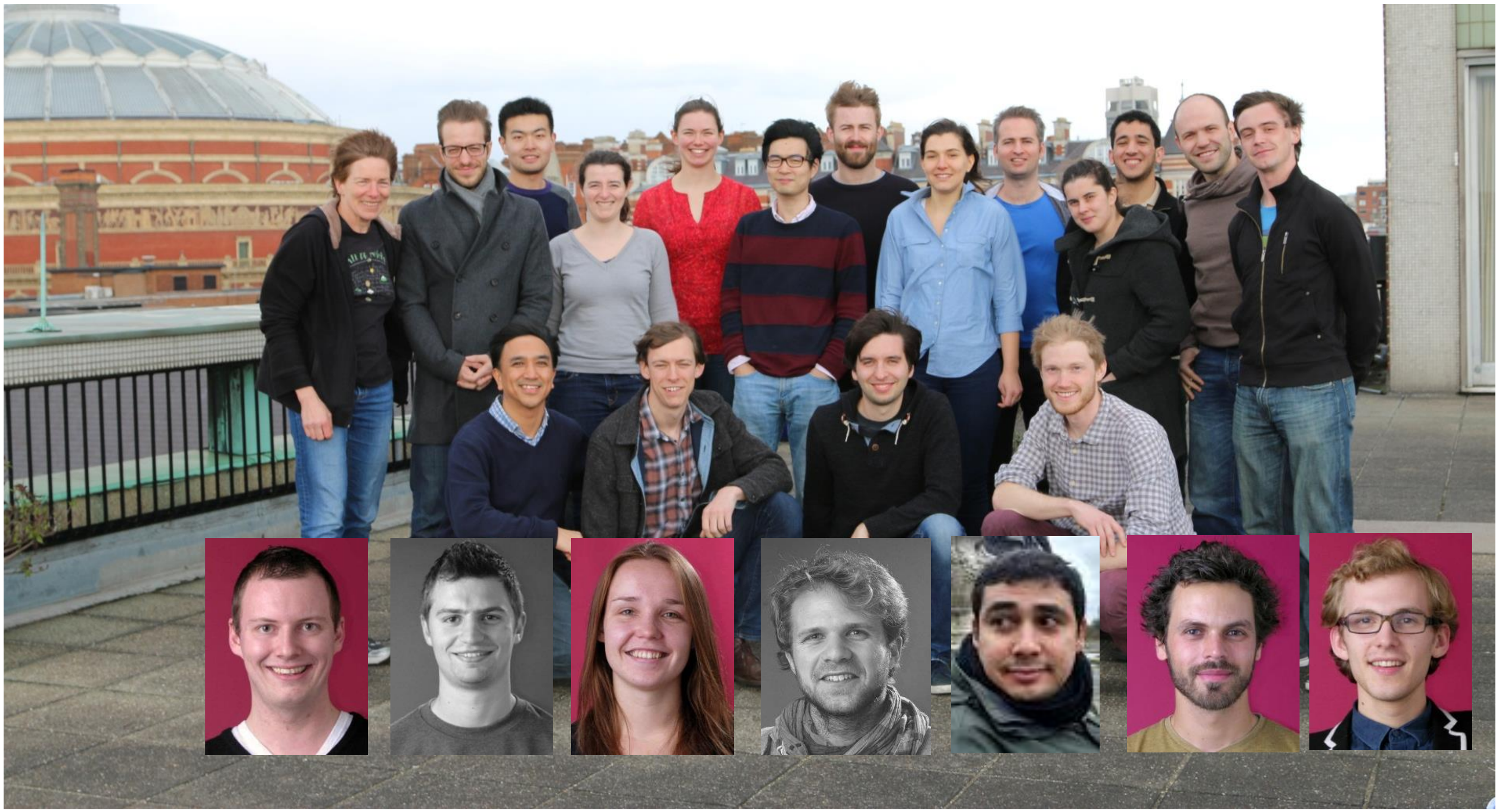
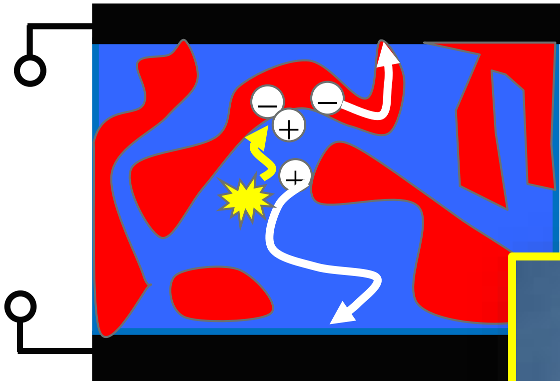
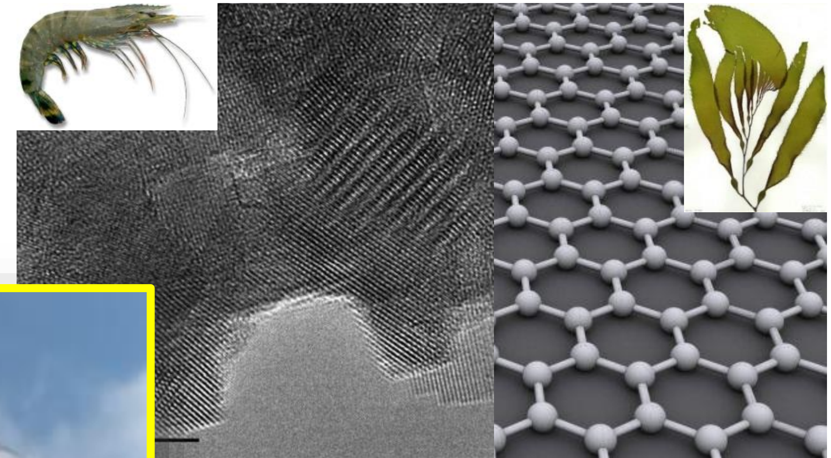
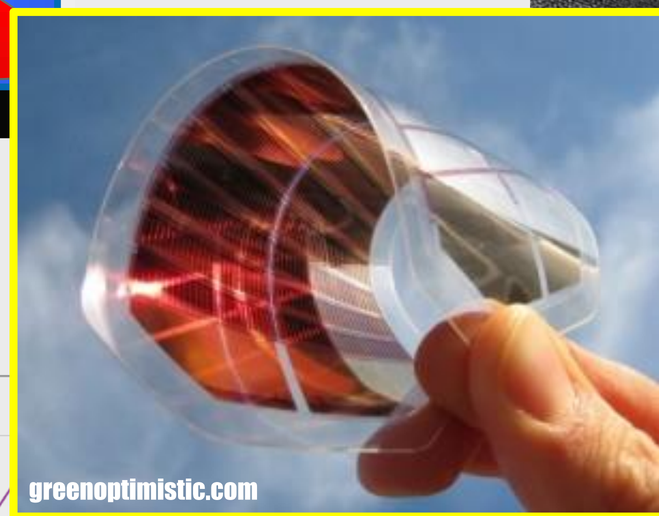
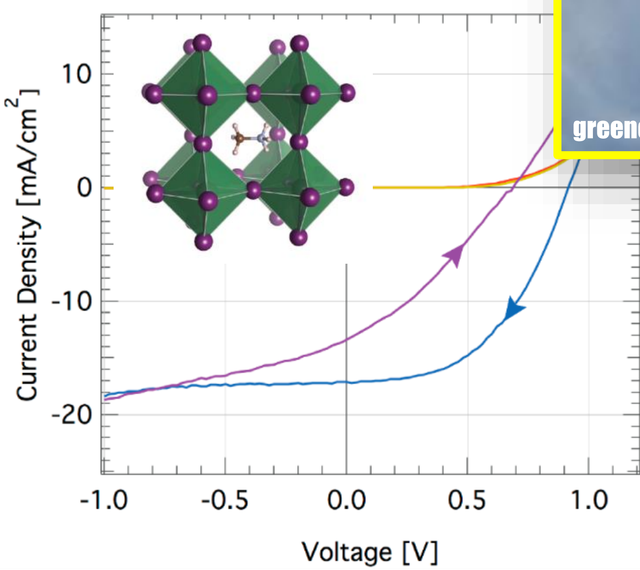


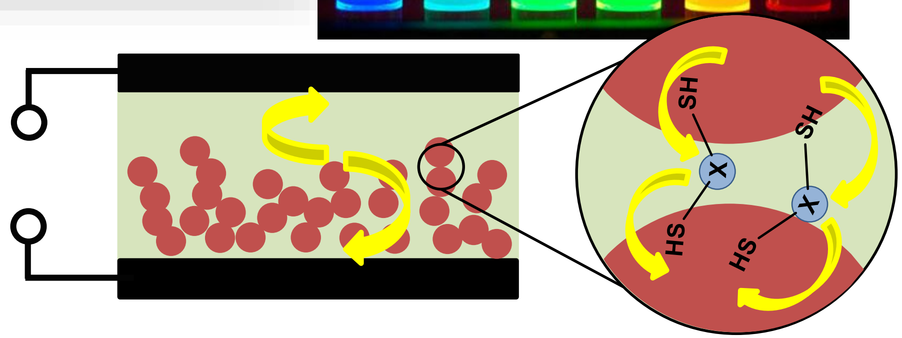
New generation solar cells



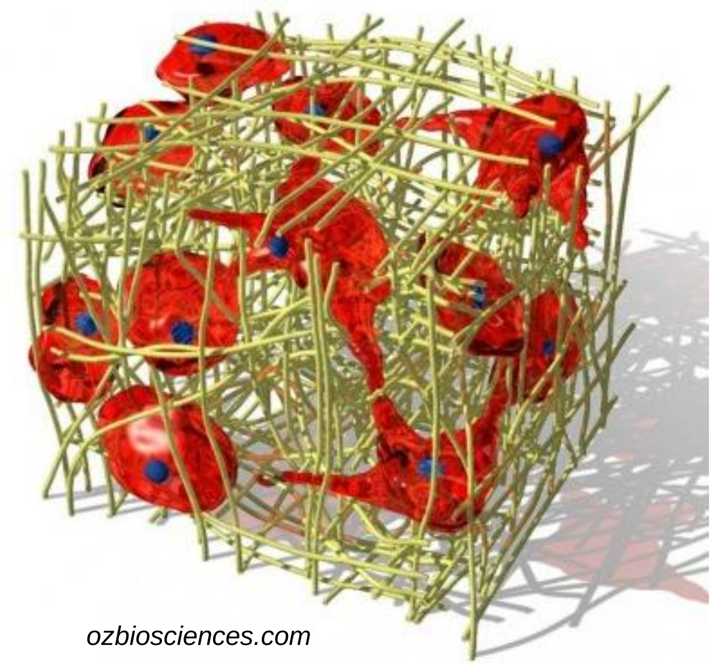








The next step: biological electronics



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Credit: University of California, Berkeley

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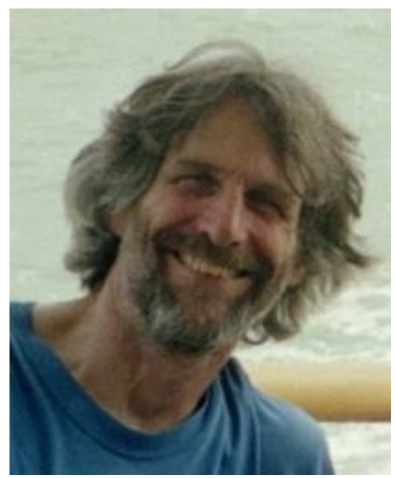
Transients of the transient photovoltage spectroscopy (TrOTTr TPV)

Phil Calado

Piers Barnes



Brian O'Regan

Dan Bryant (ICL, Chemistry)

Xiaoe Li (ICL, Chemistry)

Jenny Nelson (ICL, Physics)

James Durrant (ICL, Chemistry)

Matt Carnie (Swansea, Specific)

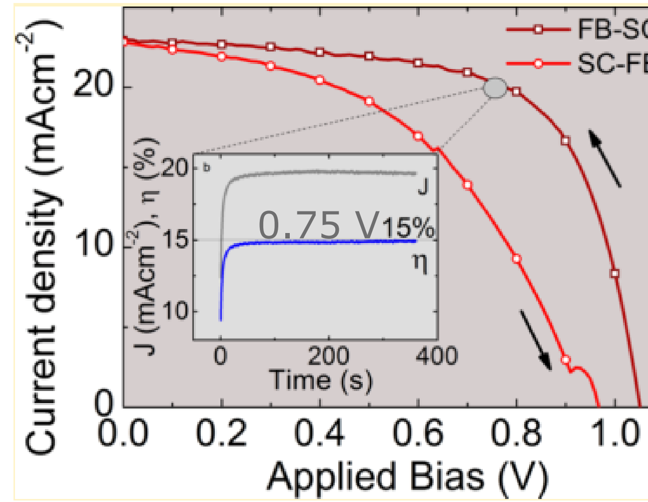
Joel Troughton (Swansea, Specific)

Hysteresis in perovskite solar cells

THE JOURNAL OF PHYSICAL CHEMISTRY Letters
Letter
pubs.acs.org/JPCL

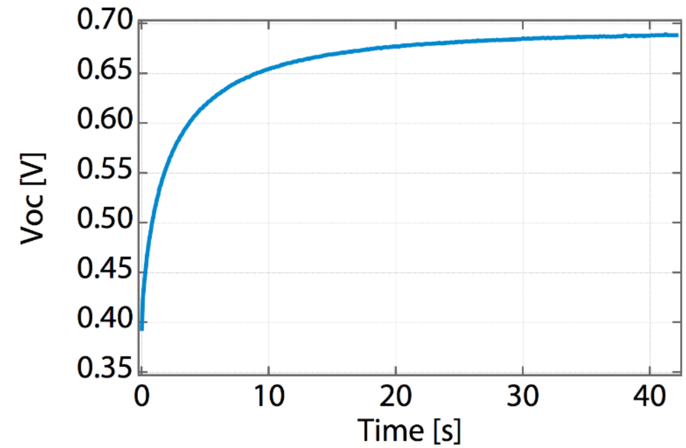
Anomalous Hysteresis in Perovskite Solar Cells

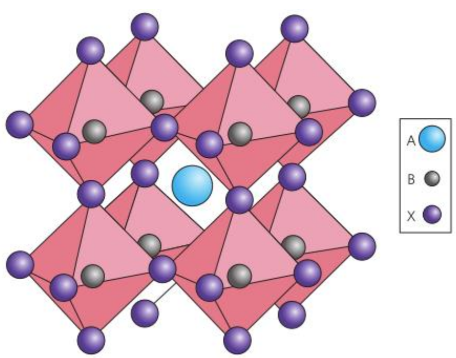
Henry J. Snaith,* Antonio Abate, James M. Ball, Giles E. Eperon, Tomas Leijtens, Nakita K. Noel, Samuel D. Stranks, Jacob Tse-Wei Wang, Konrad Wojciechowski, and Wei Zhang



- Current-Voltage scans exhibit hysteresis between forward and reverse scans

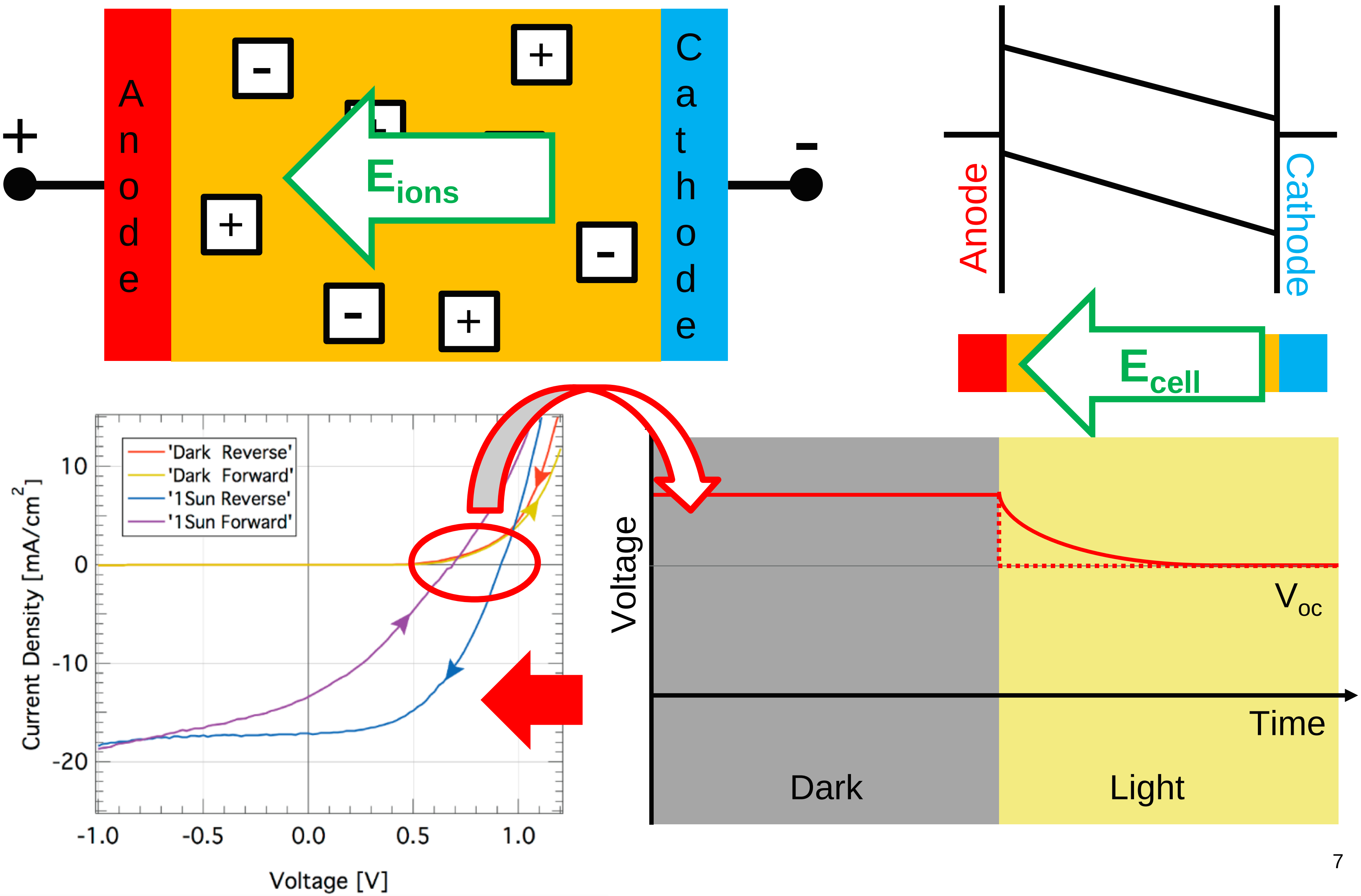
- Short circuit current and open circuit voltage exhibits relaxation on the timescale of seconds



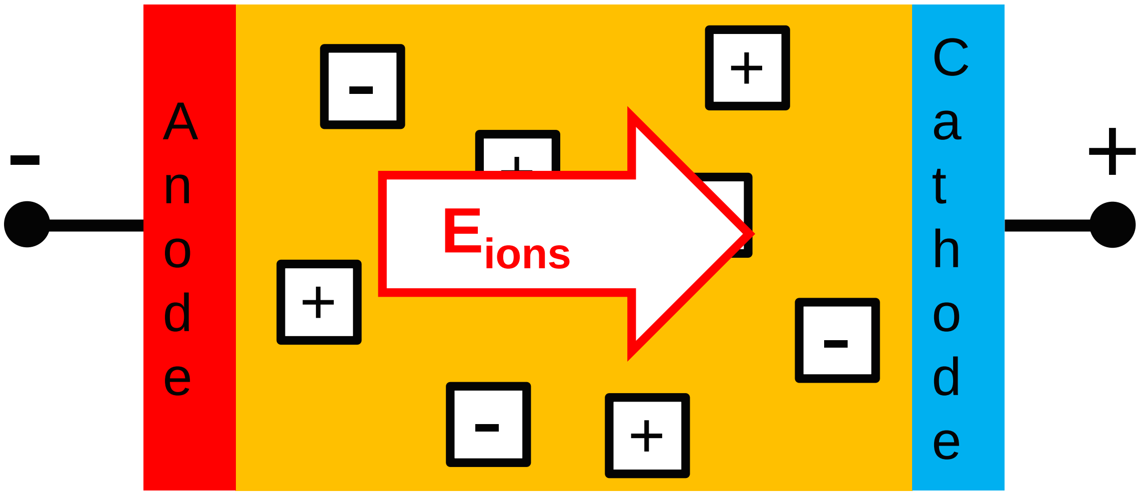


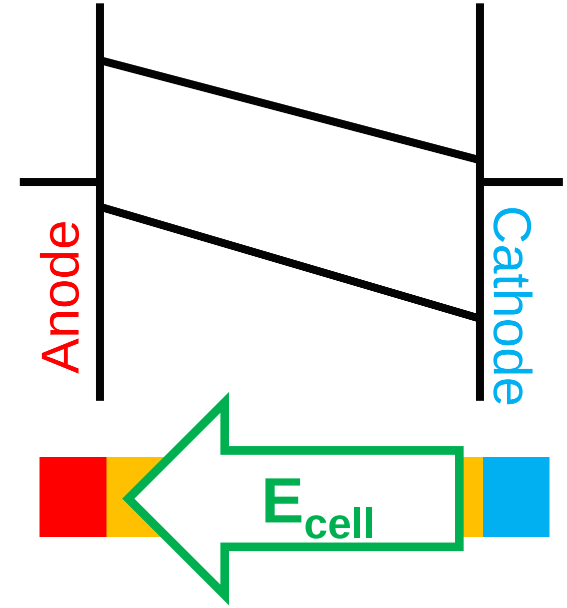
$CH_3NH_3PbI_3$
(MAPI)

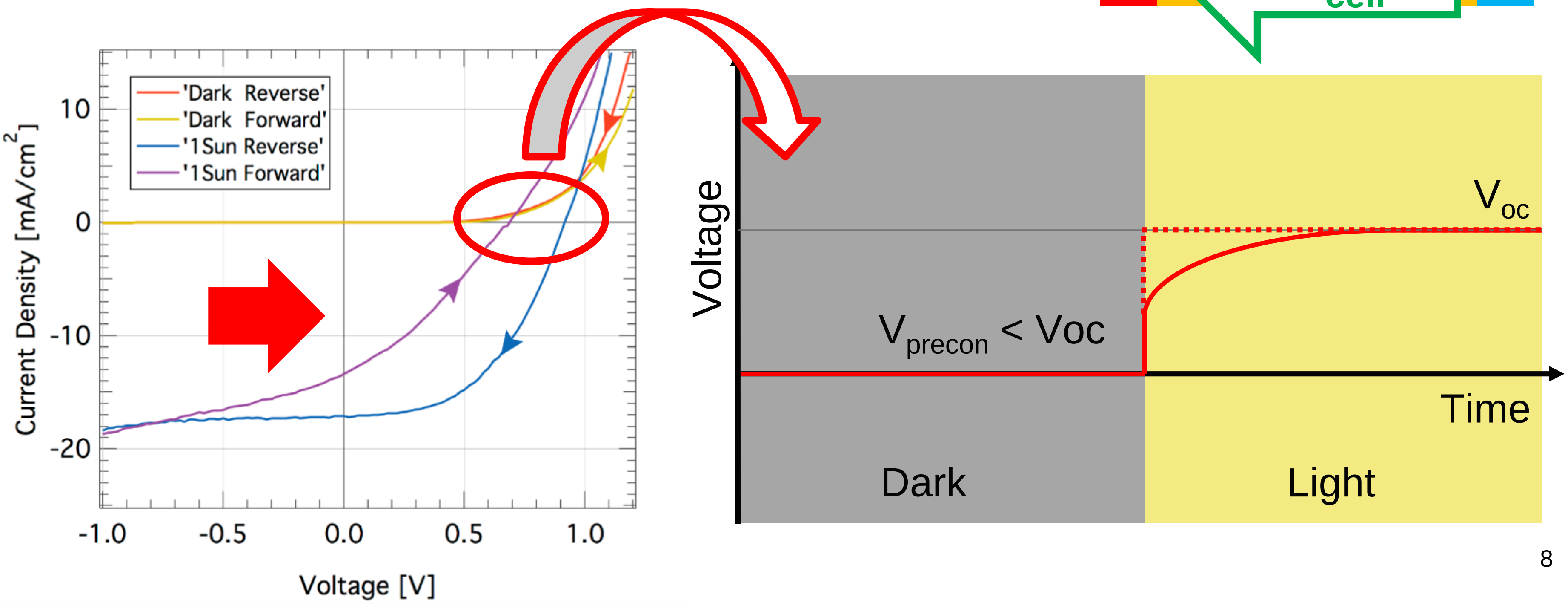
Ion migration



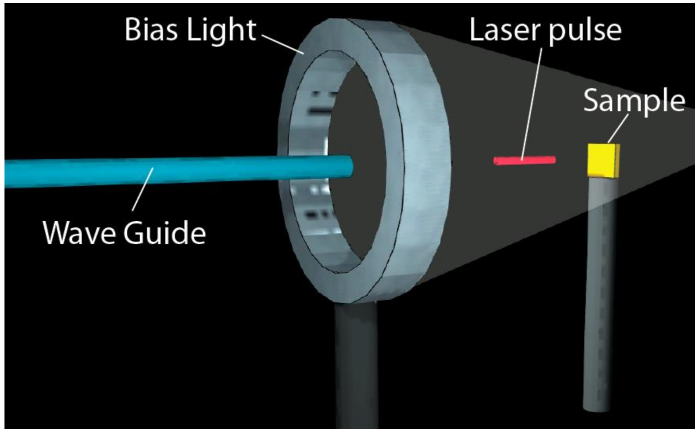
Ion migration

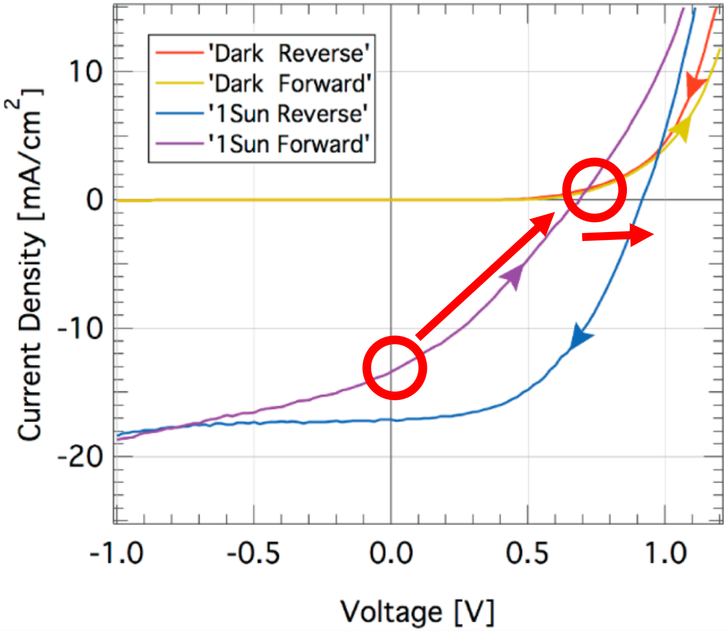


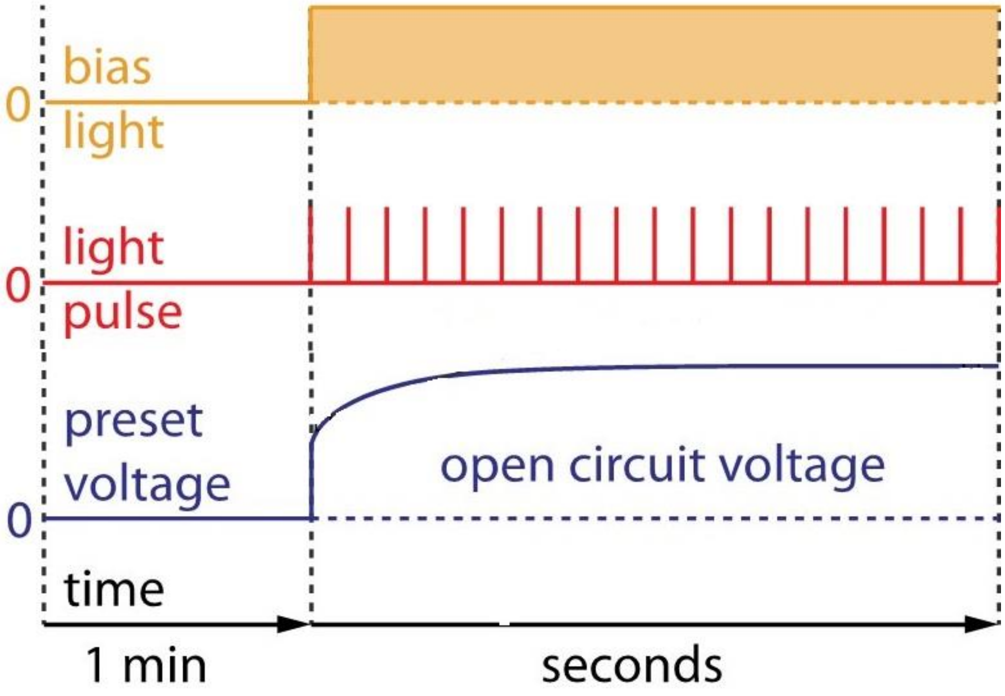




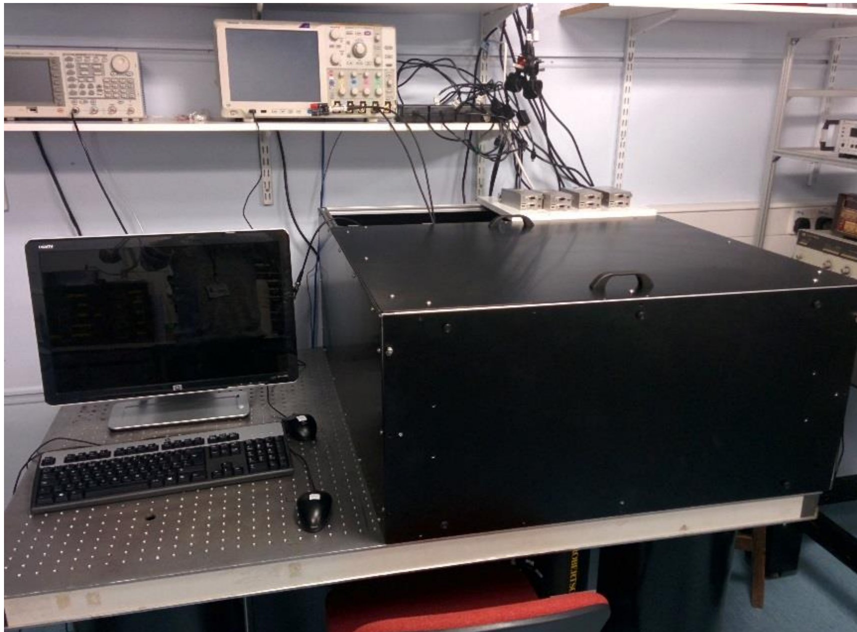
Transients of the transient (TrOTTr) photovoltage measurements

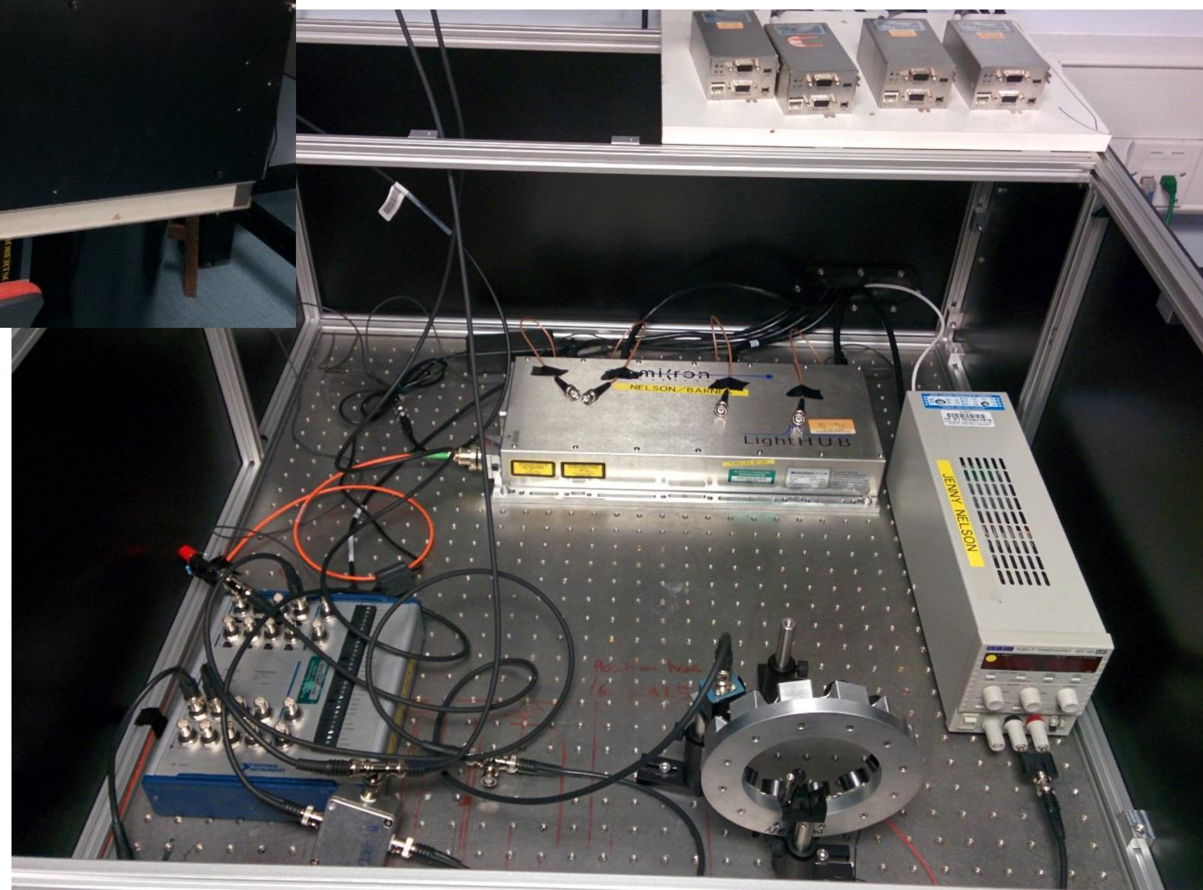




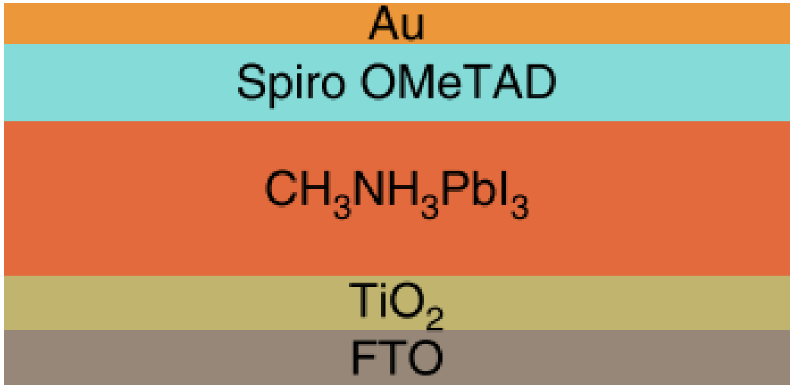


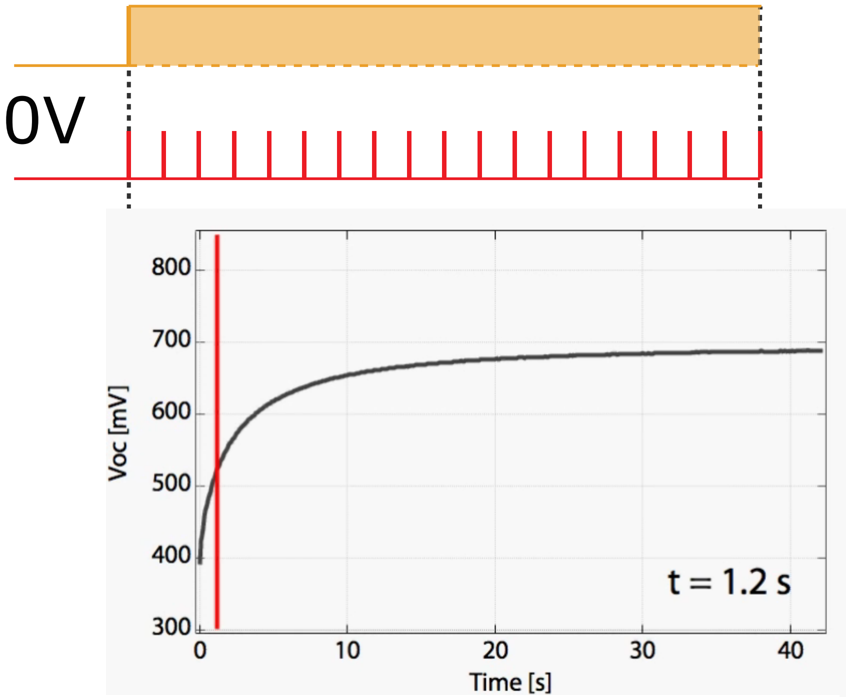
The TrOTTr rig

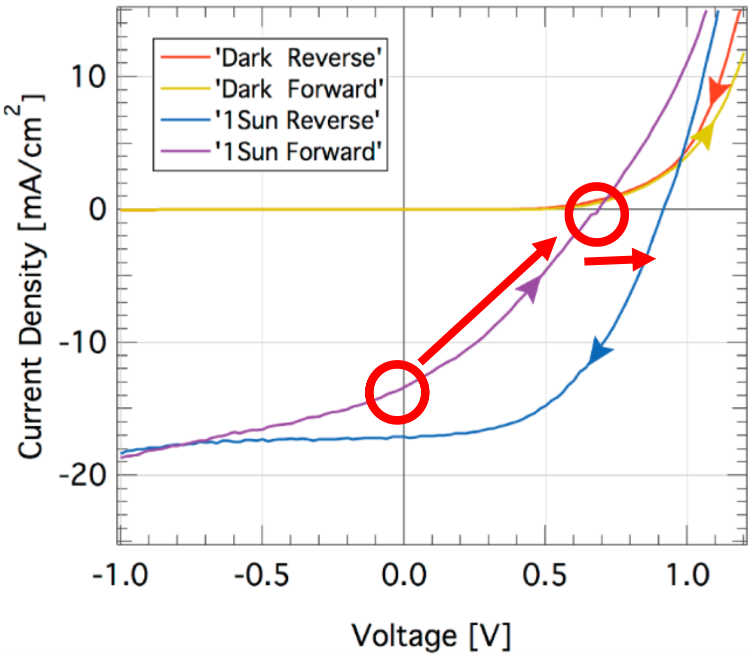




TiO_2 bottom cathode architecture







Ionic charge accumulation

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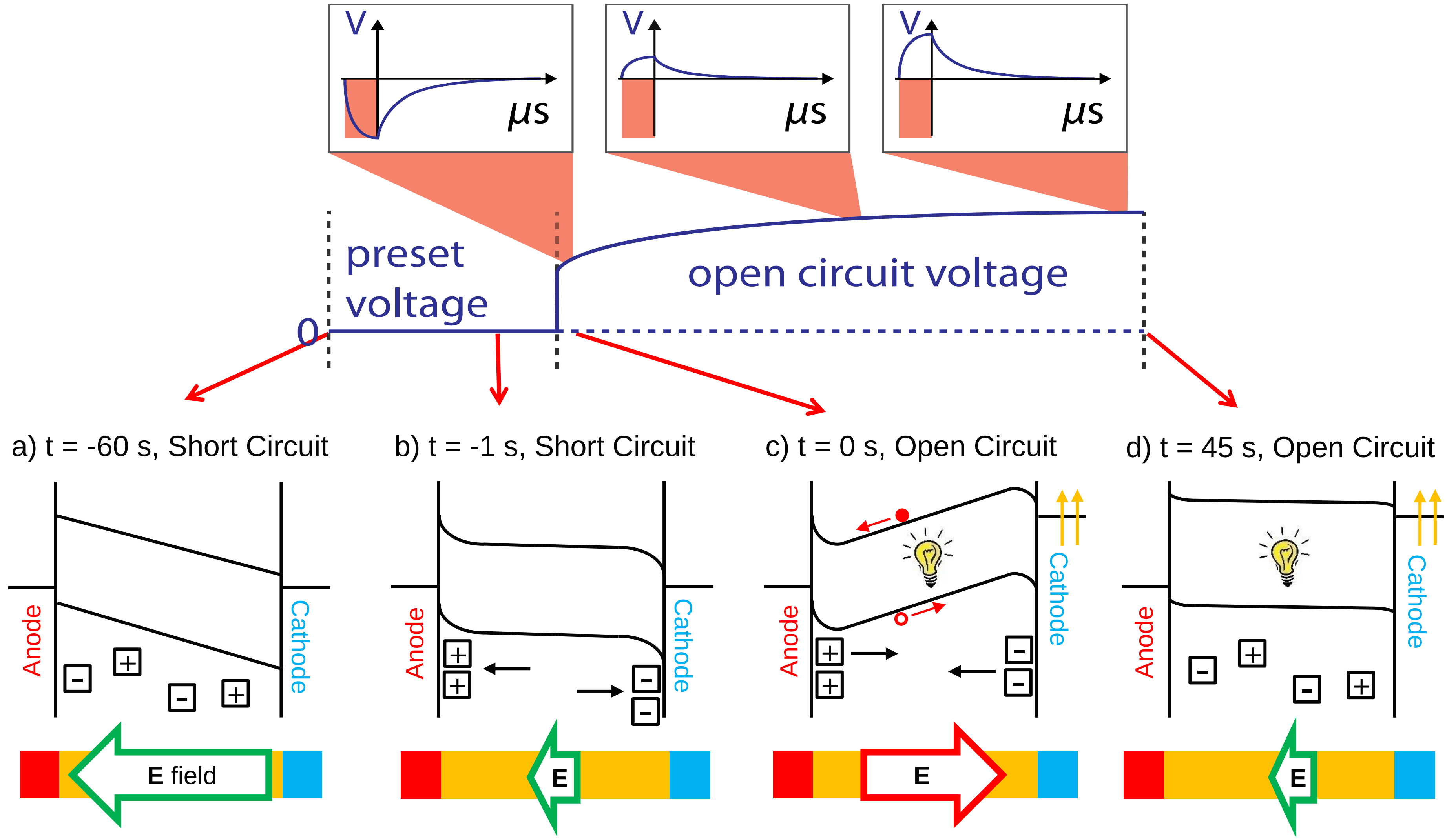

Tress et al. EES 2015; Zhang *Mater Horiz* RSC 2015;
Xiao et al. Nat Mater. 2014; Eames et al. Nat. Comm. 2015

Hysteresis-free devices!

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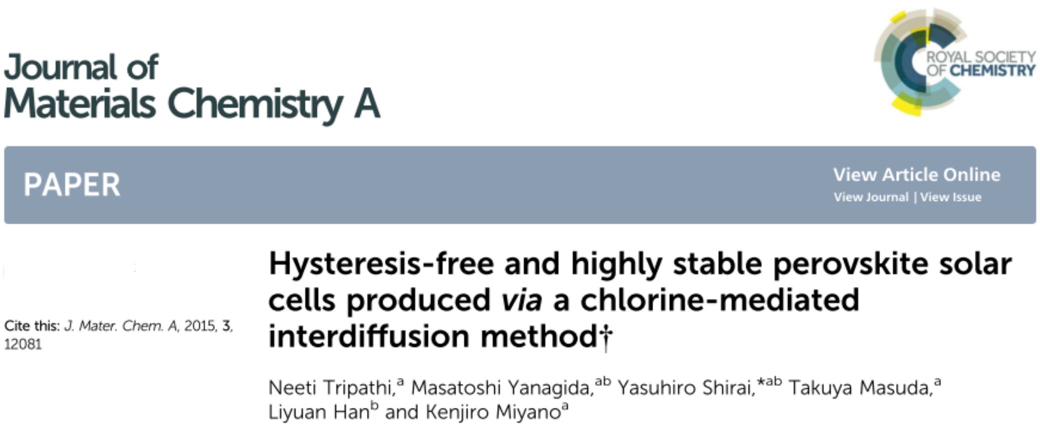
Journal of Materials Chemistry A

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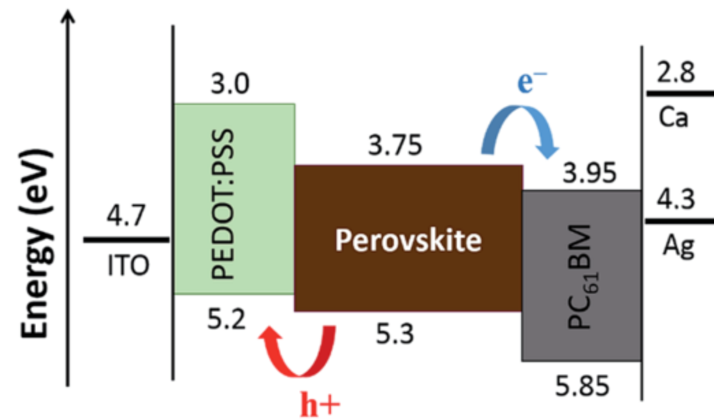
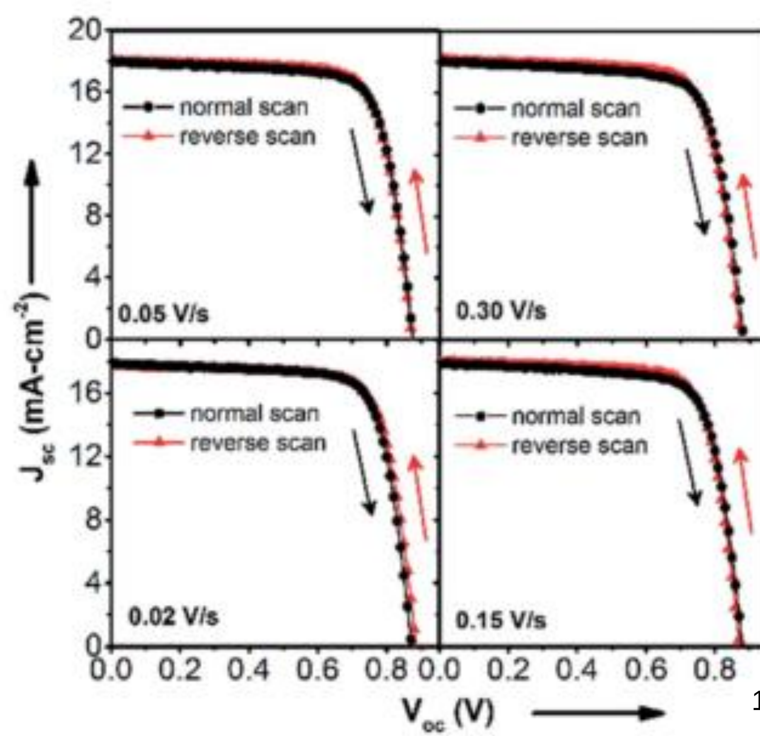
Hysteresis-free and highly stable perovskite solar cells produced *via* a chlorine-mediated interdiffusion method†

Neeti Tripathi,[a] Masatoshi Yanagida,[ab] Yasuhiro Shirai,*[ab] Takuya Masuda,[a] Liyuan Han[b] and Kenjiro Miyano[a]

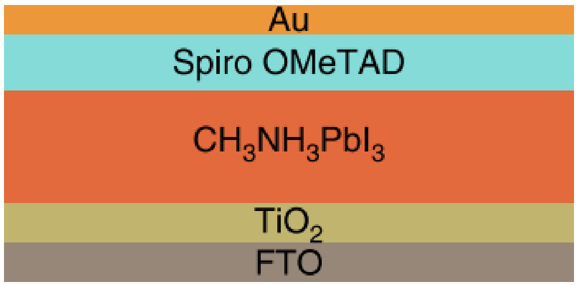


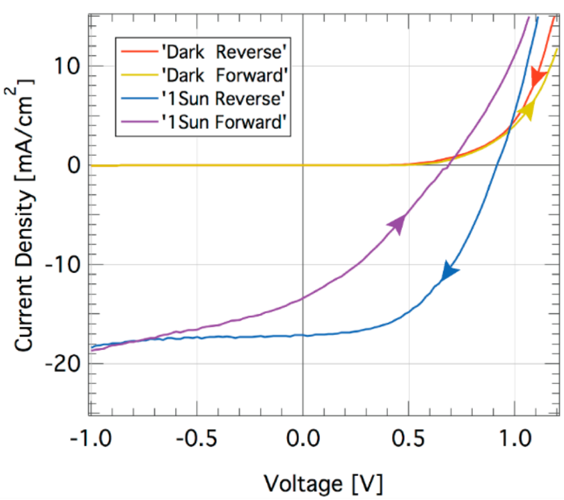
- Changing contact materials appears to alter *J-V* hysteresis



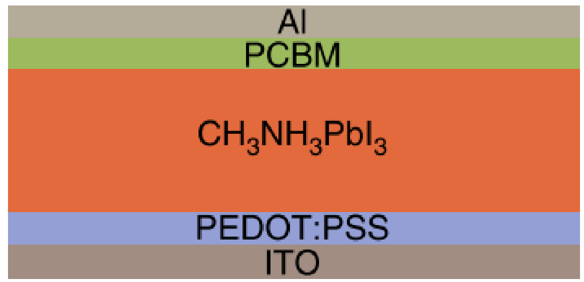
Hysteresis depends on the contact materials

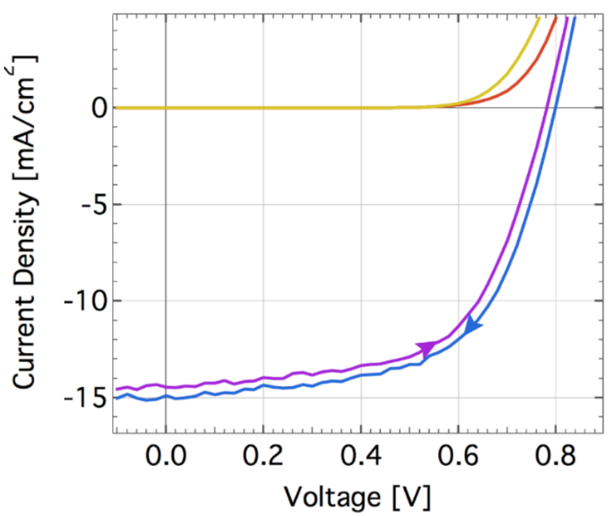
Bottom cathode – TiO_2



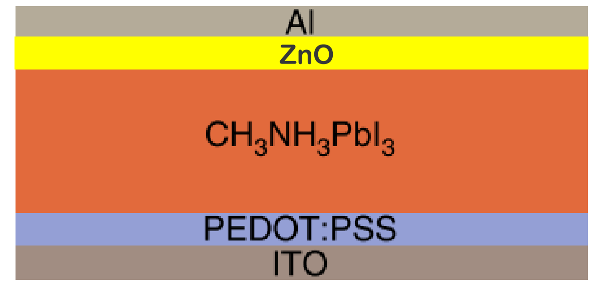


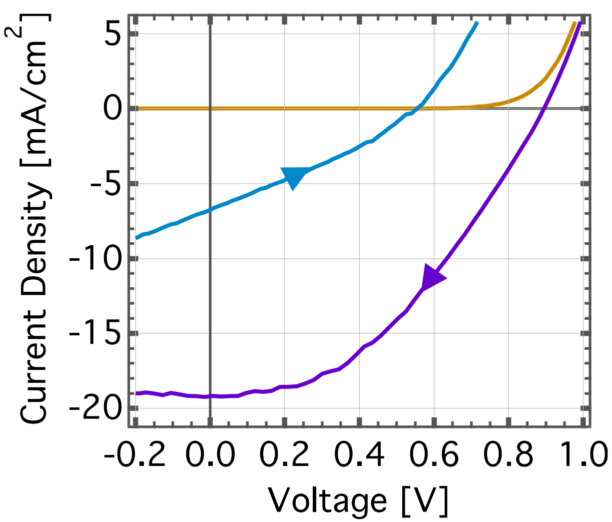
Top cathode - PCBM





Top cathode - ZnO





PCBM top cathode architecture

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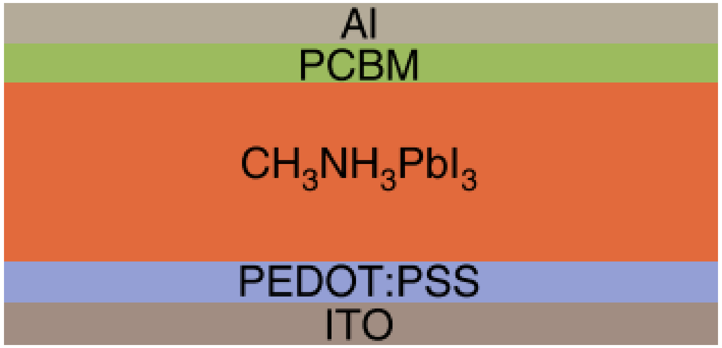
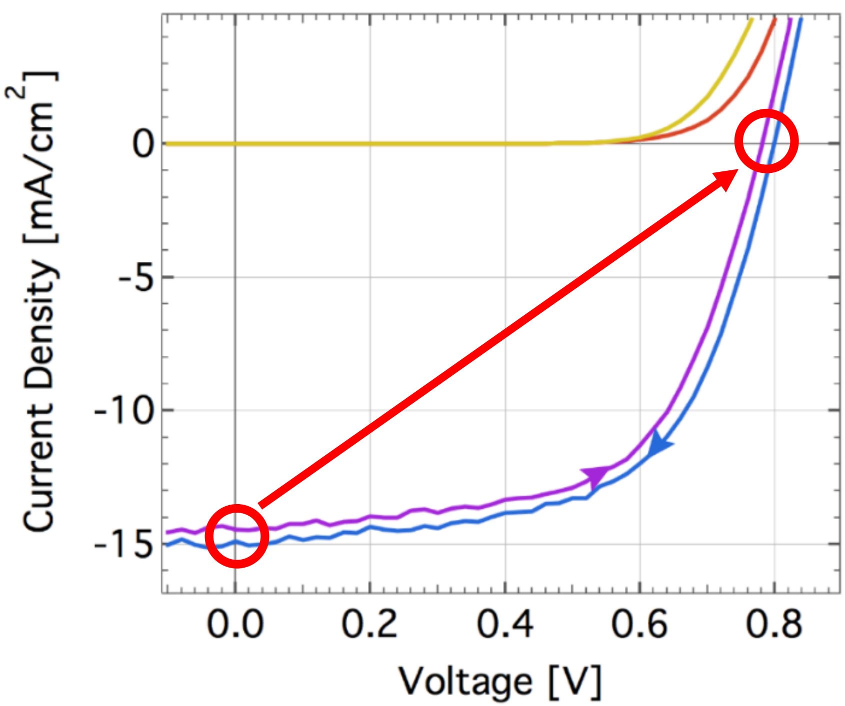
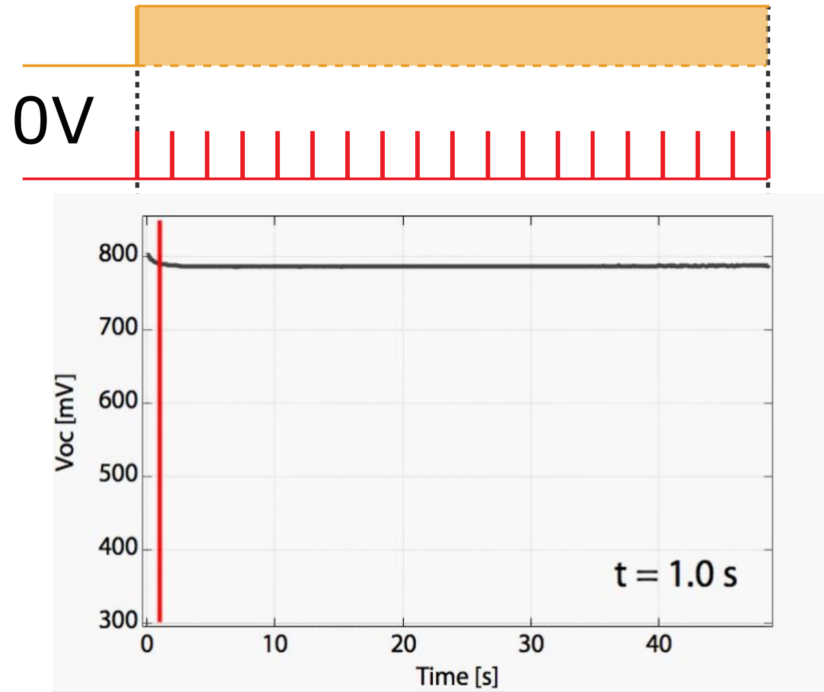
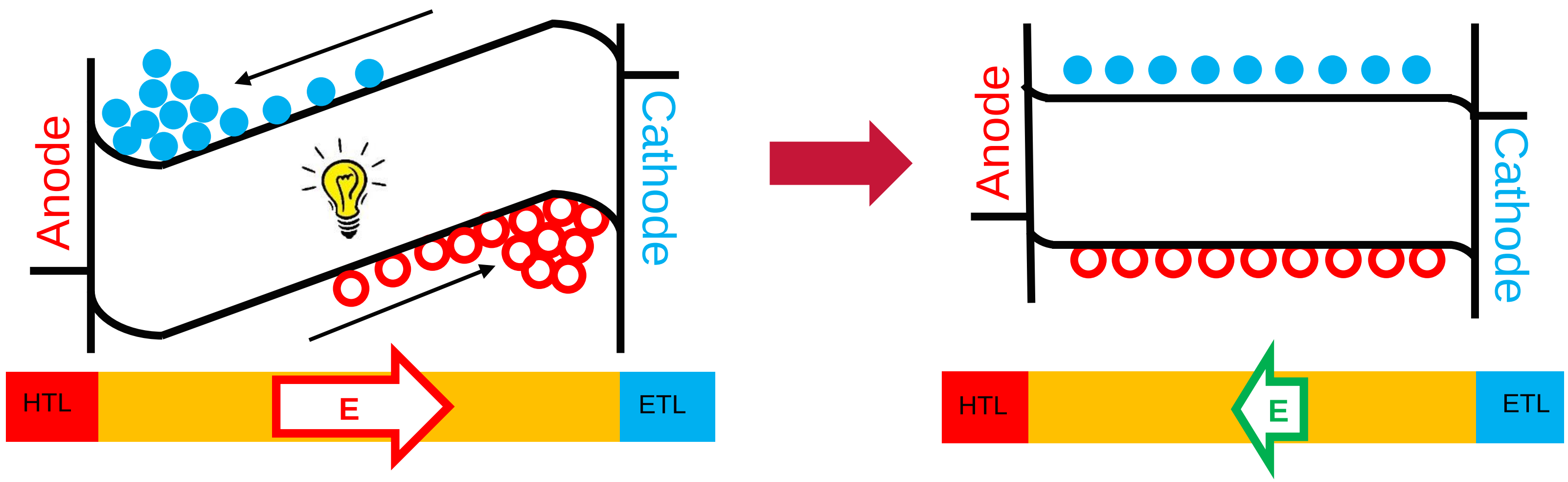


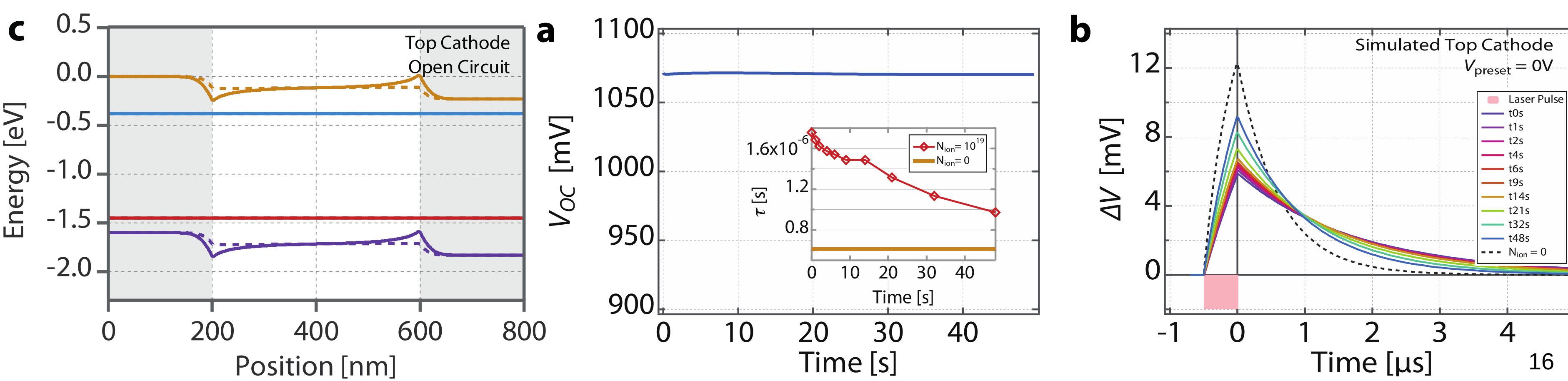




The role of interfacial recombination

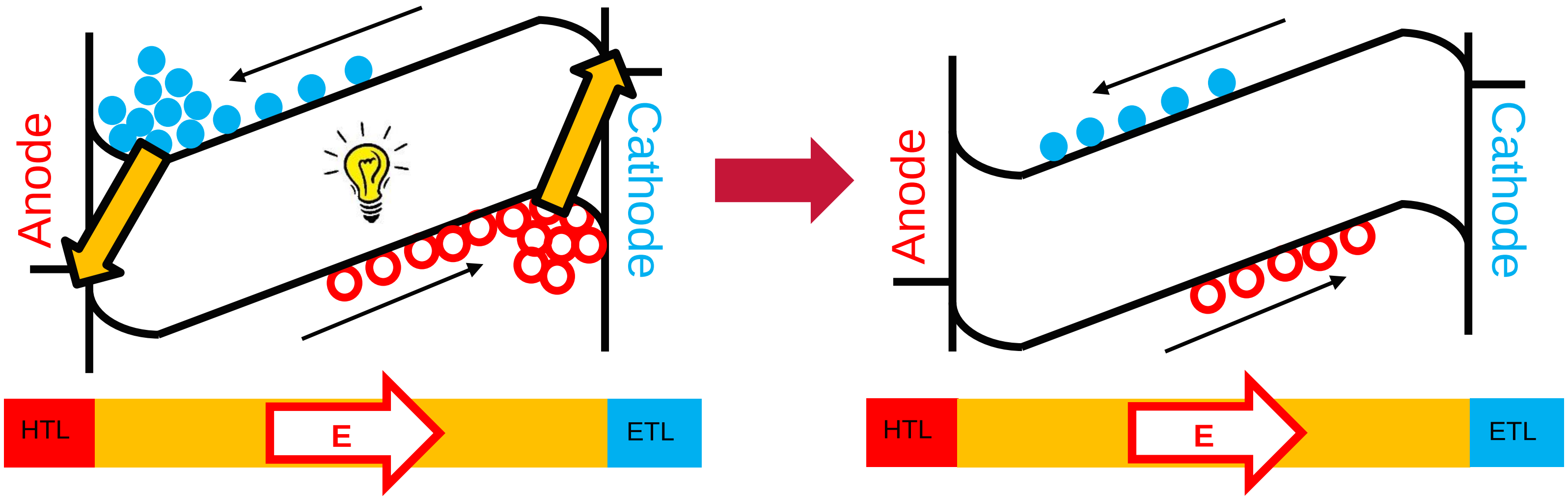
- Without surface recombination, photogenerated charge carriers flood device and screen ionic charge

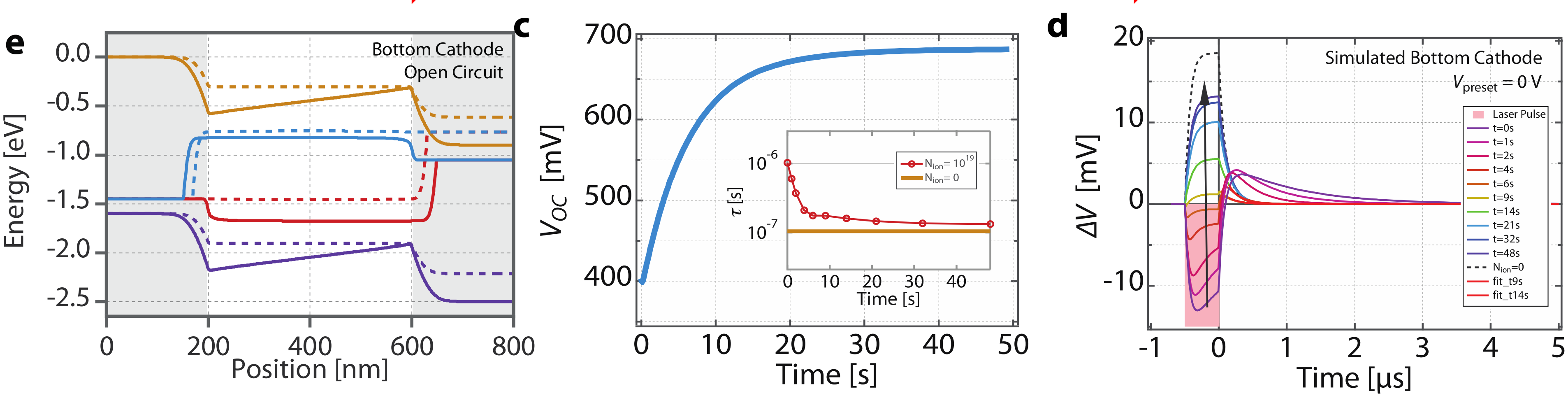




The role of interfacial recombination

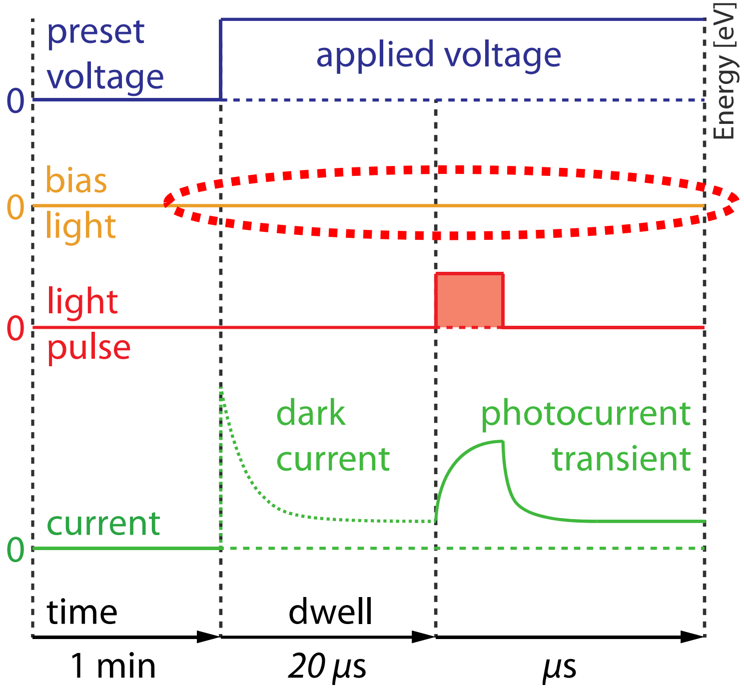
- With surface recombination, photo-carrier concentrations are low- ionic charge dominates **E**-field distribution

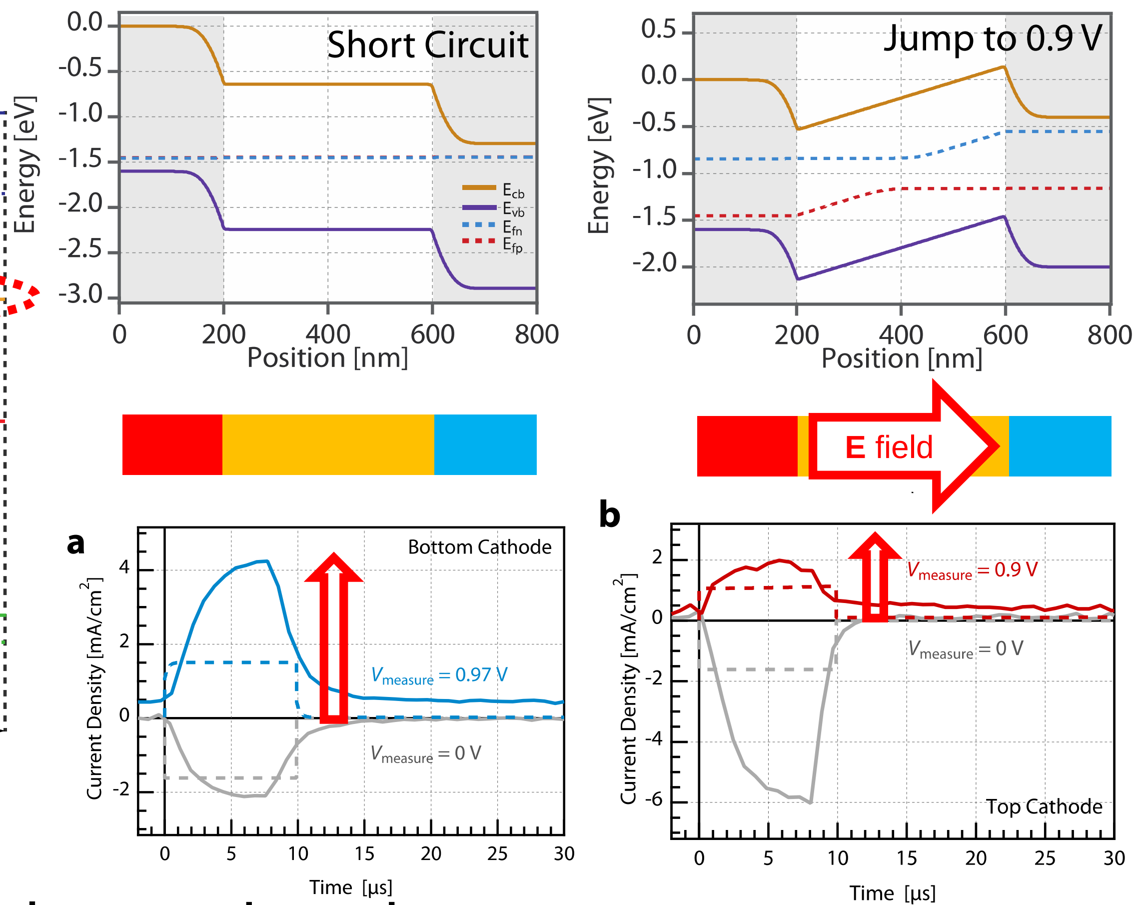




Van Reenen et al. JPCL 2015, DOI: 10.1021/acs.jpclett.5b01645

Jump-to-voltage photocurrent current transient



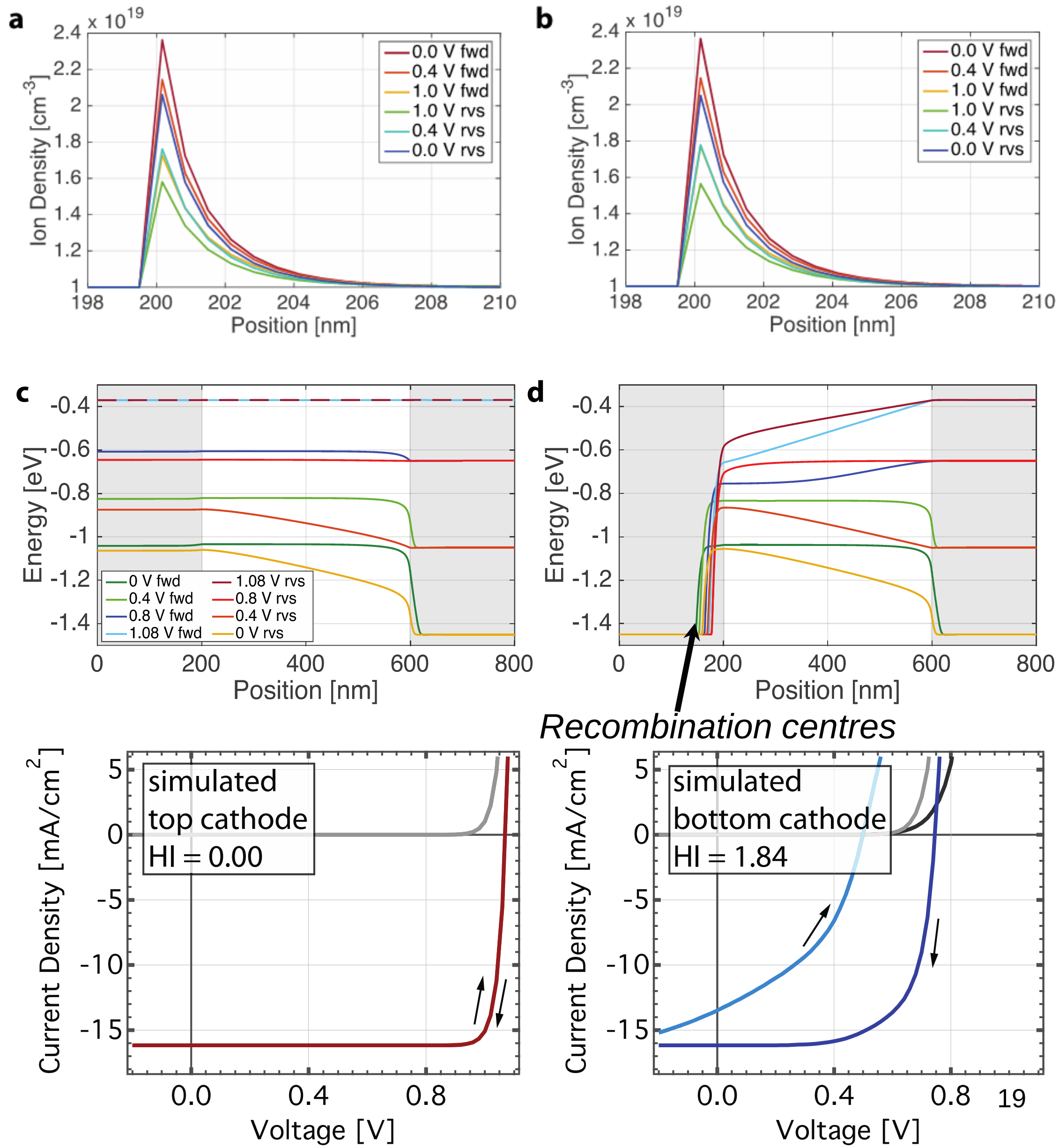


No bias light → few background carriers

***Positive** transient photocurrent observed in both architectures indicating reverse field*

Conclusions

- Mobile ions are present in the device regardless of hysteresis.
- Surface recombination determines whether a reverse electric field at Voc is detectable or not. It also affects the extraction efficiency at 0<V<Voc.
- Hysteresis can be reproduced in JV curves by switching ON or OFF the surface recombination, while allowing for ion migration.



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How Does the Photo-oxidation of Fullerenes Affect the Behaviour of OPV Devices?


Jason Röhr


Beth Rice

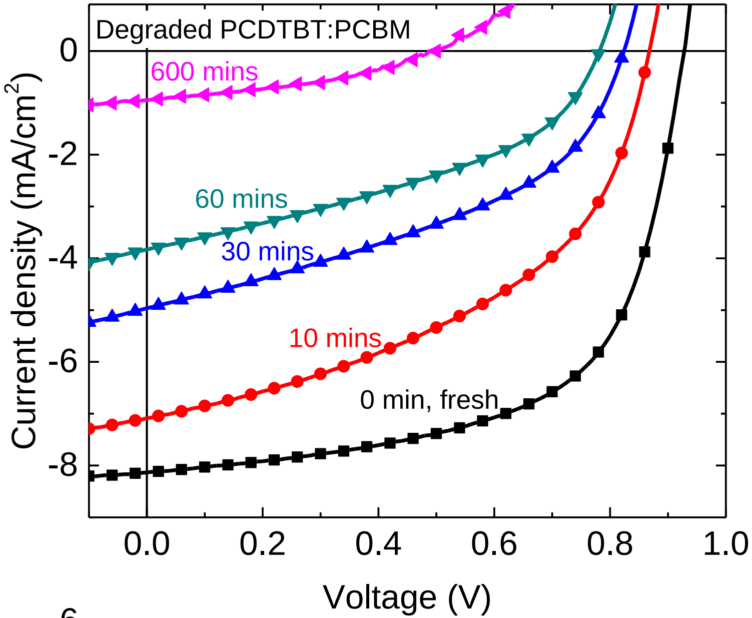

Alexandre De Castro Maciel

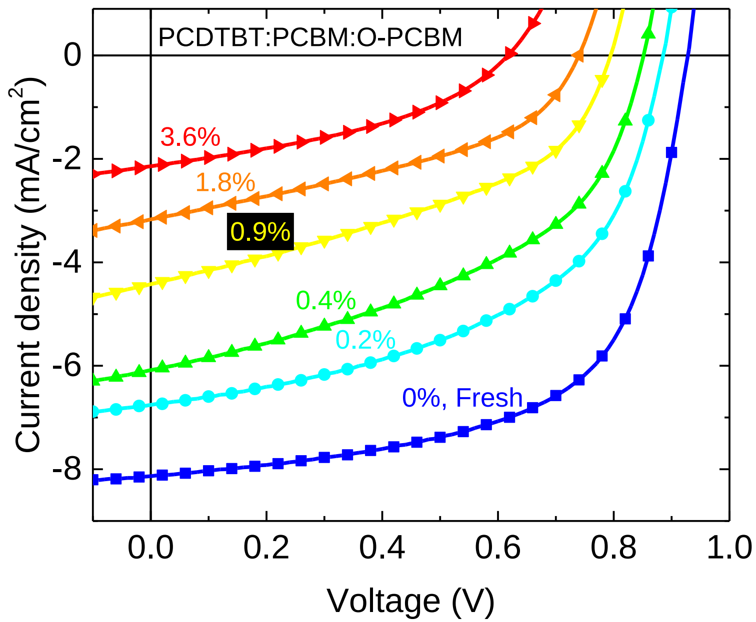

Jenny Nelson

James R. Durrant (Imperial, Chemistry)
Jiaying Wu (Imperial, Chemistry

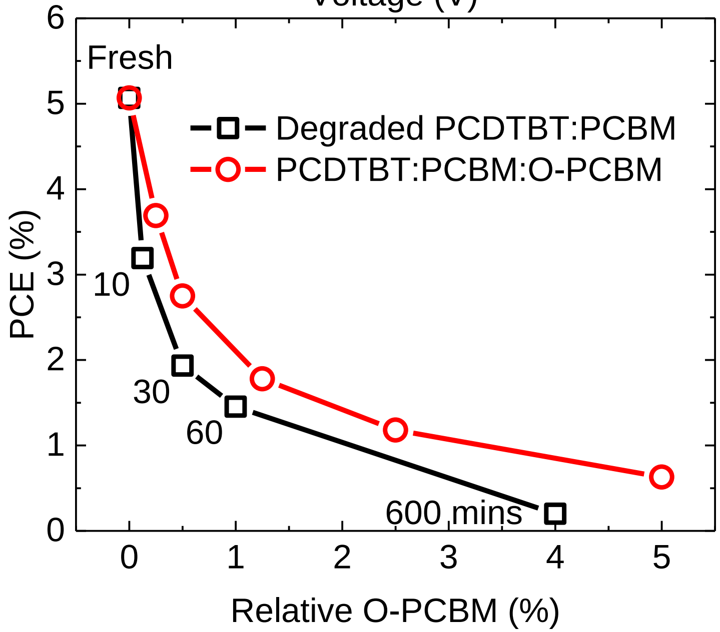
Wing C. Tsoi (Swansea)
Zhe Li (Swansea)
Harrison K. H. Lee (Swansea)
Emily Speller (Swansea)

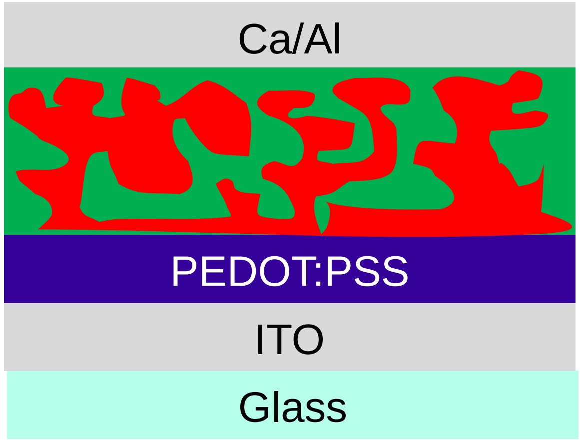
Photo-oxidation of fullerene





Harrison K. H. Lee





PCDTBT:PCBM

Photo-oxidation of PCBM

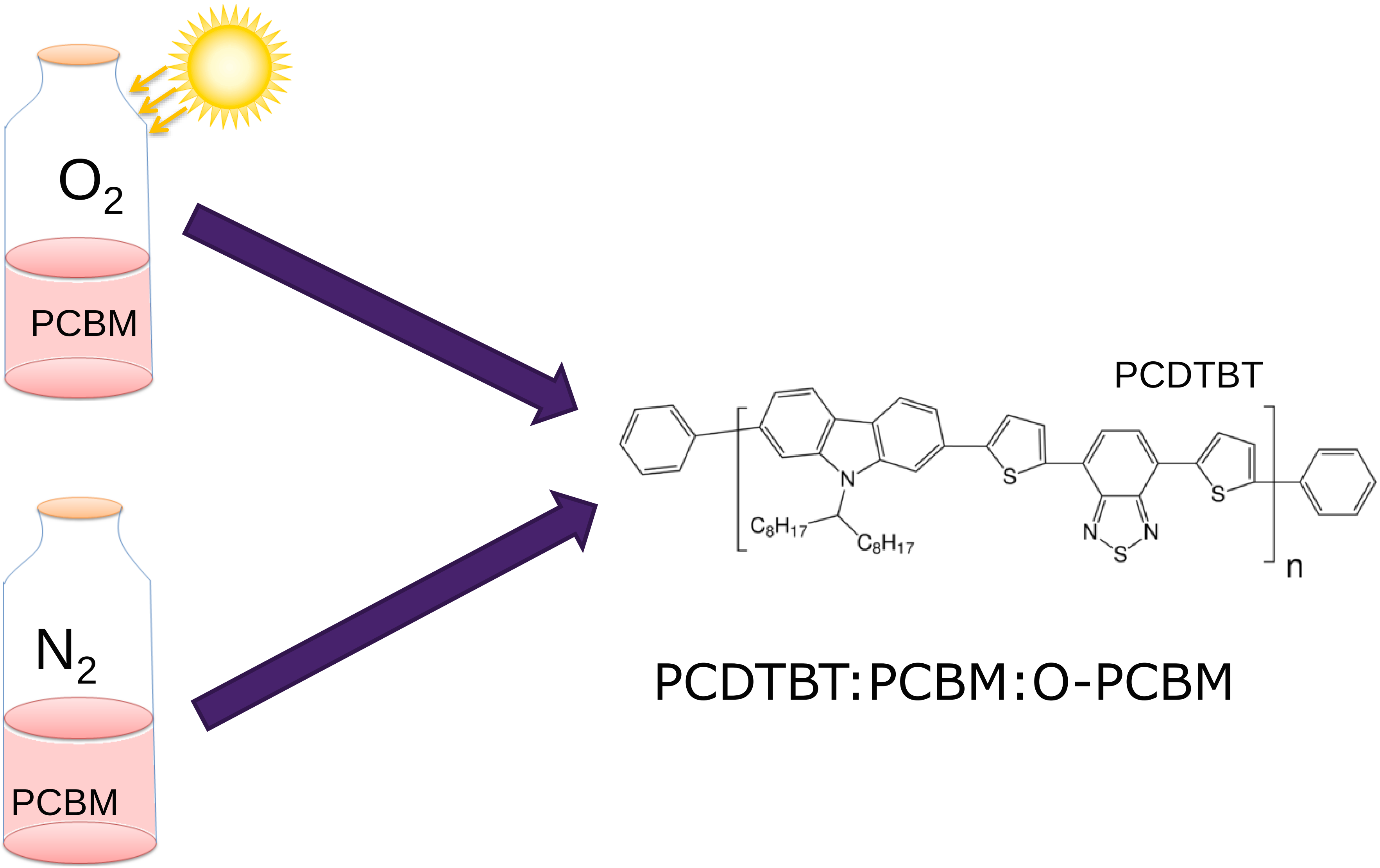
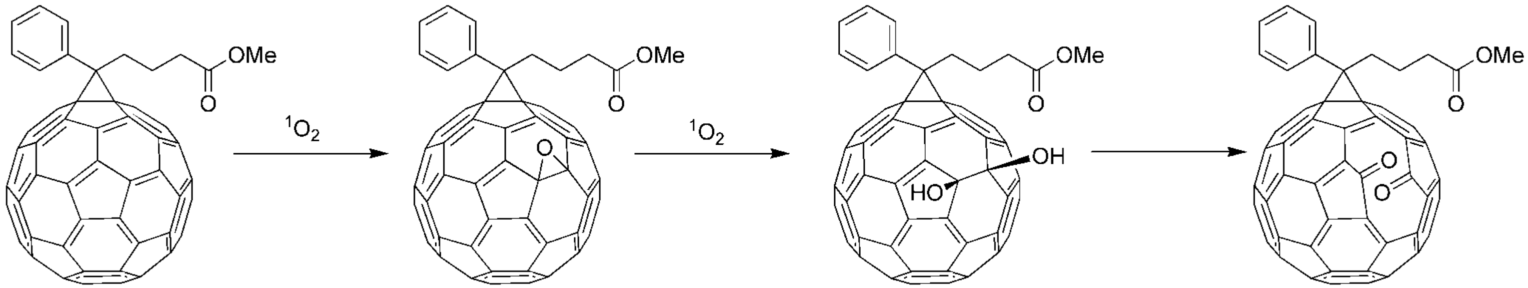
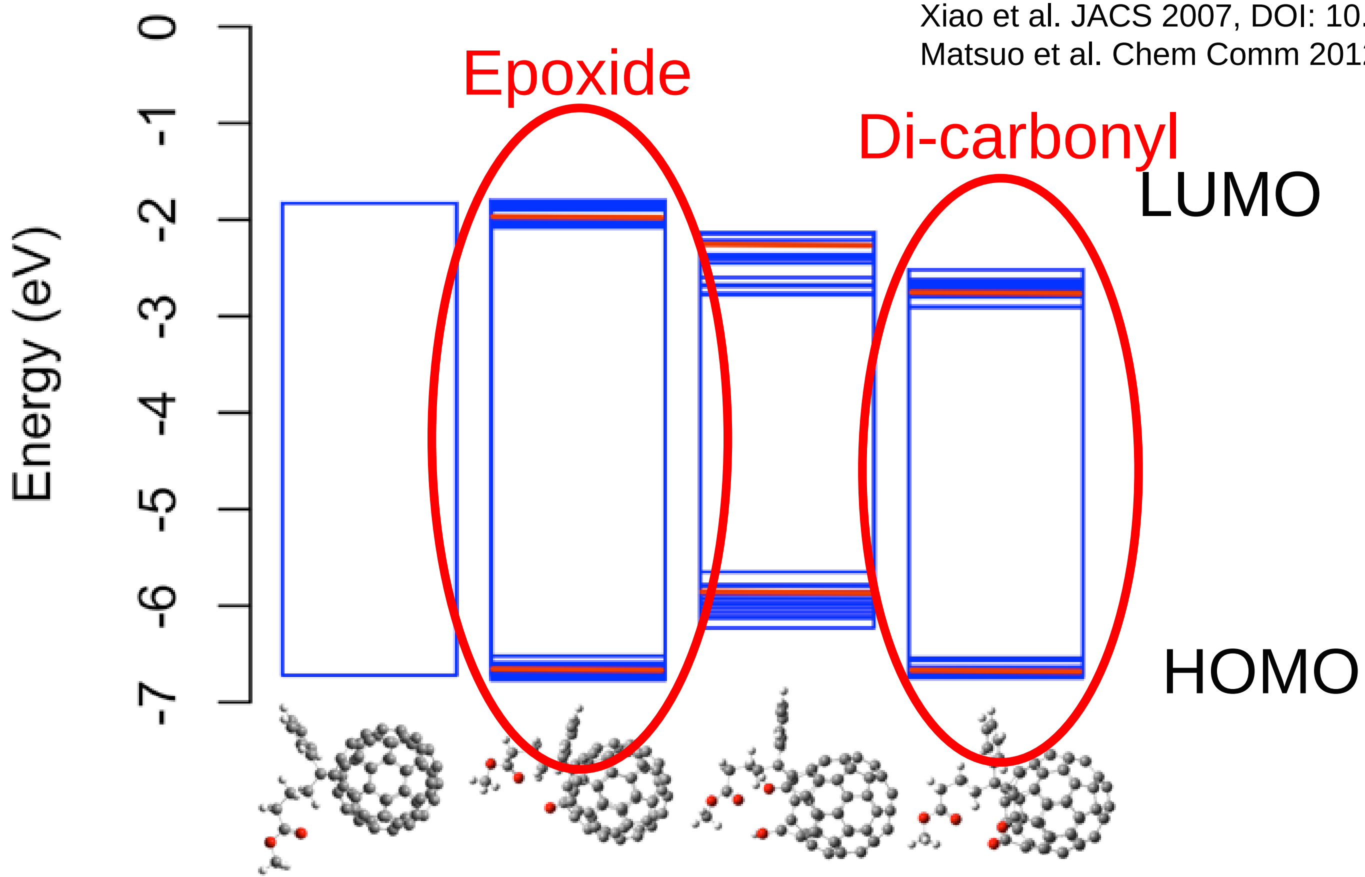


Photo-oxidation products

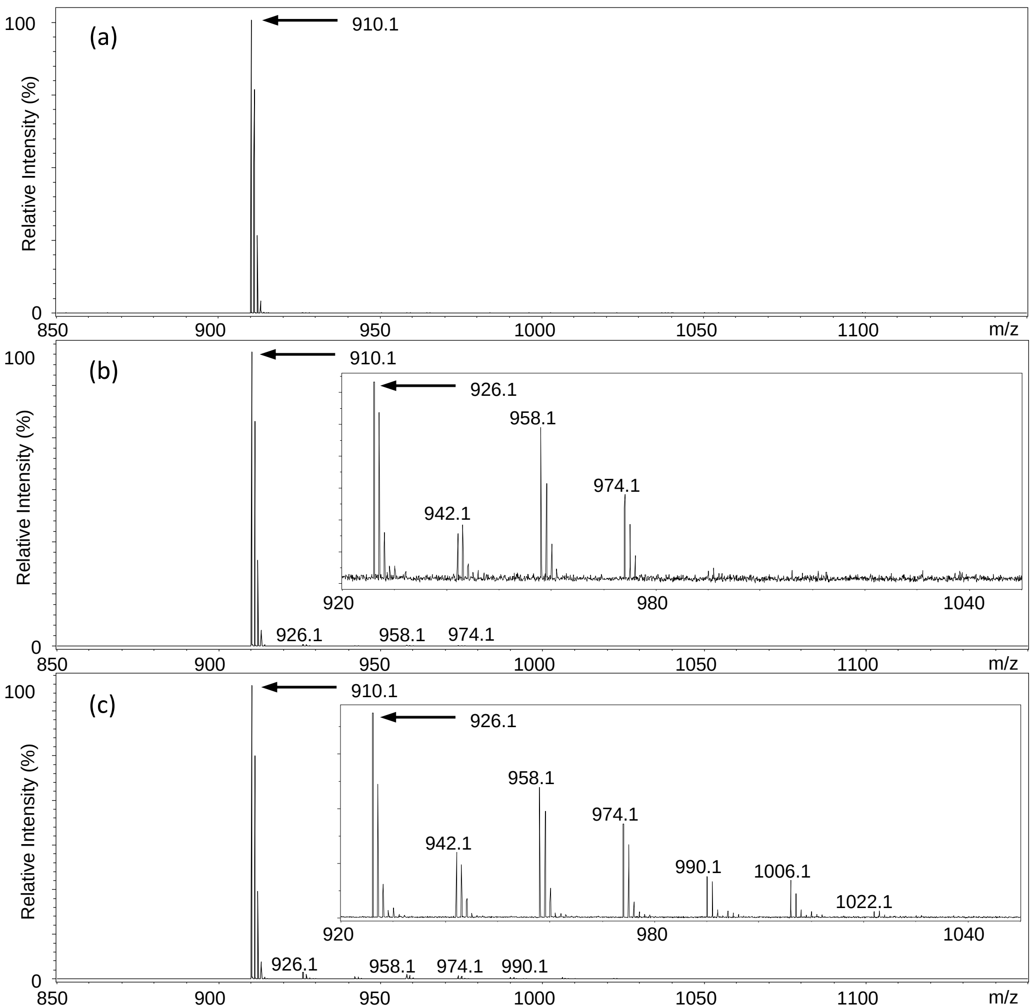


Xiao et al. JACS 2007, DOI: 10.1021/ja0763798
Matsuo et al. Chem Comm 2012, DOI: 10.1039/c2cc30262d



Beth Rice

Mass spectrometry

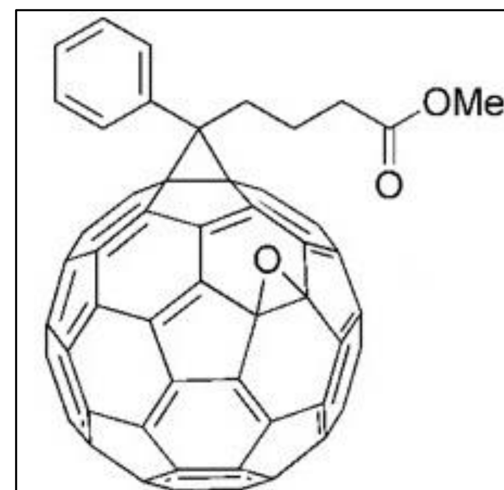


Fresh PCBM

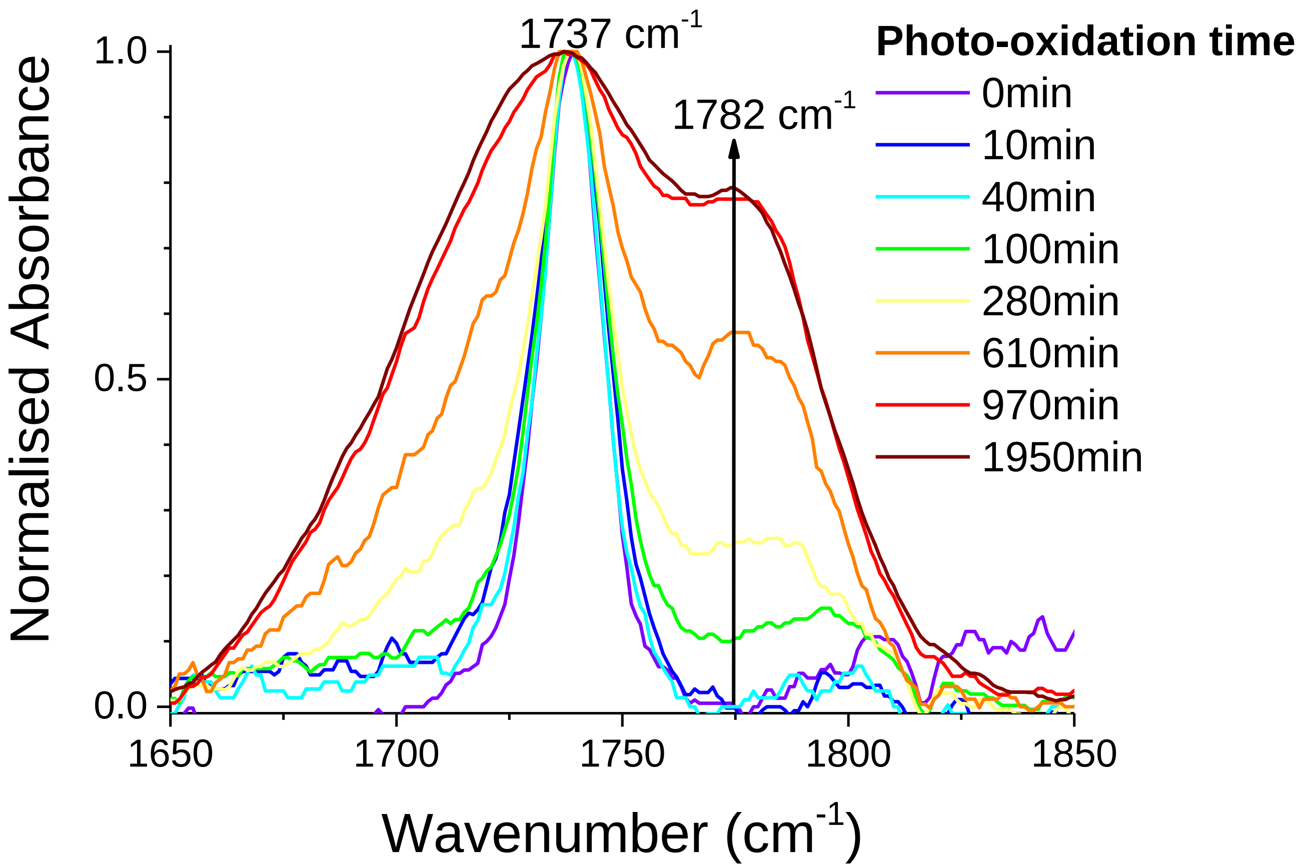
Degraded PCBM in blend with PCDTBT

Degraded PCBM in solution

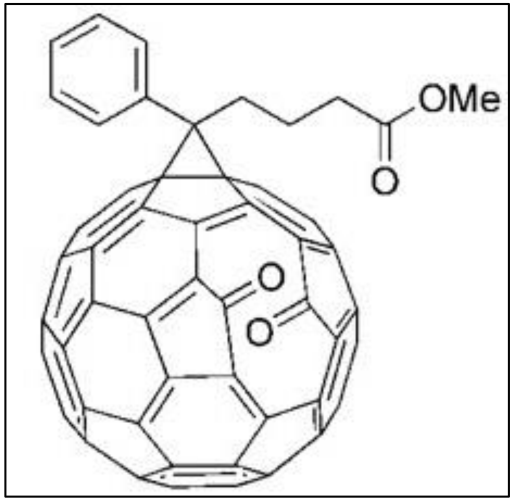
Mark F. Wyatt



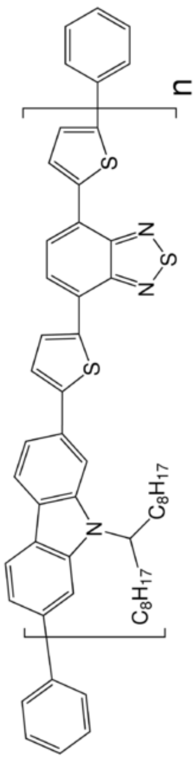
IR spectroscopy

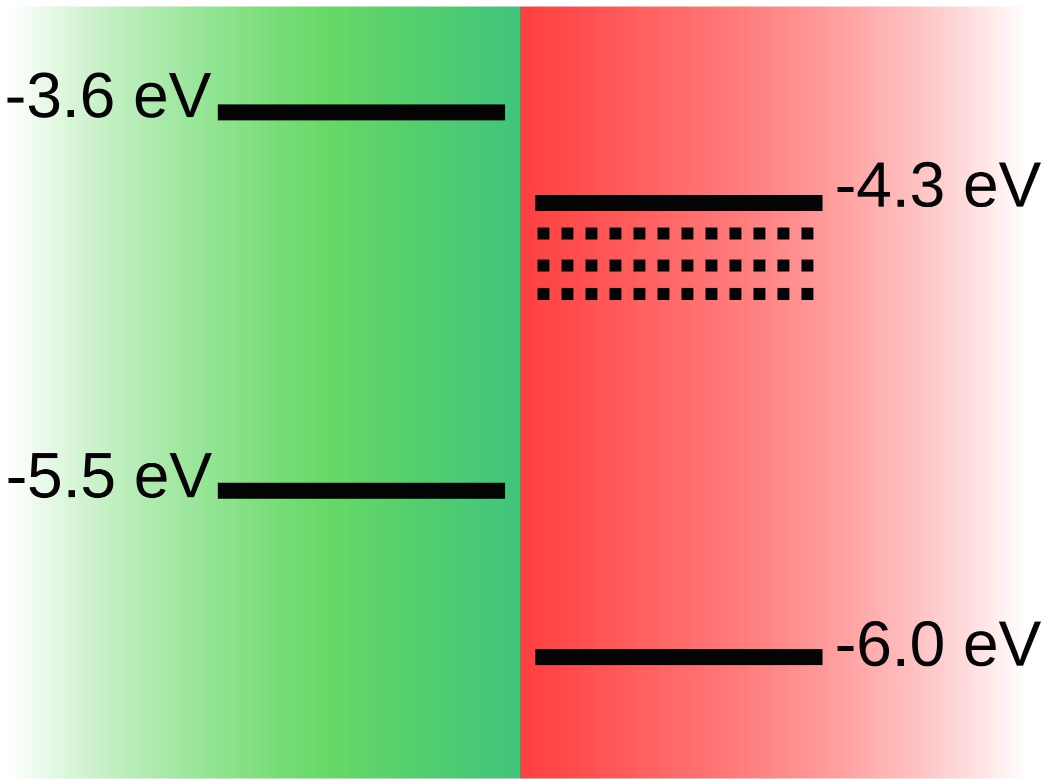


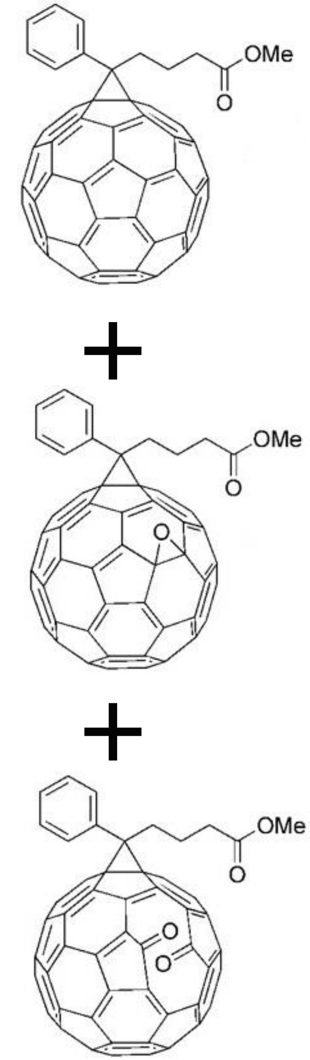
Emily Speller



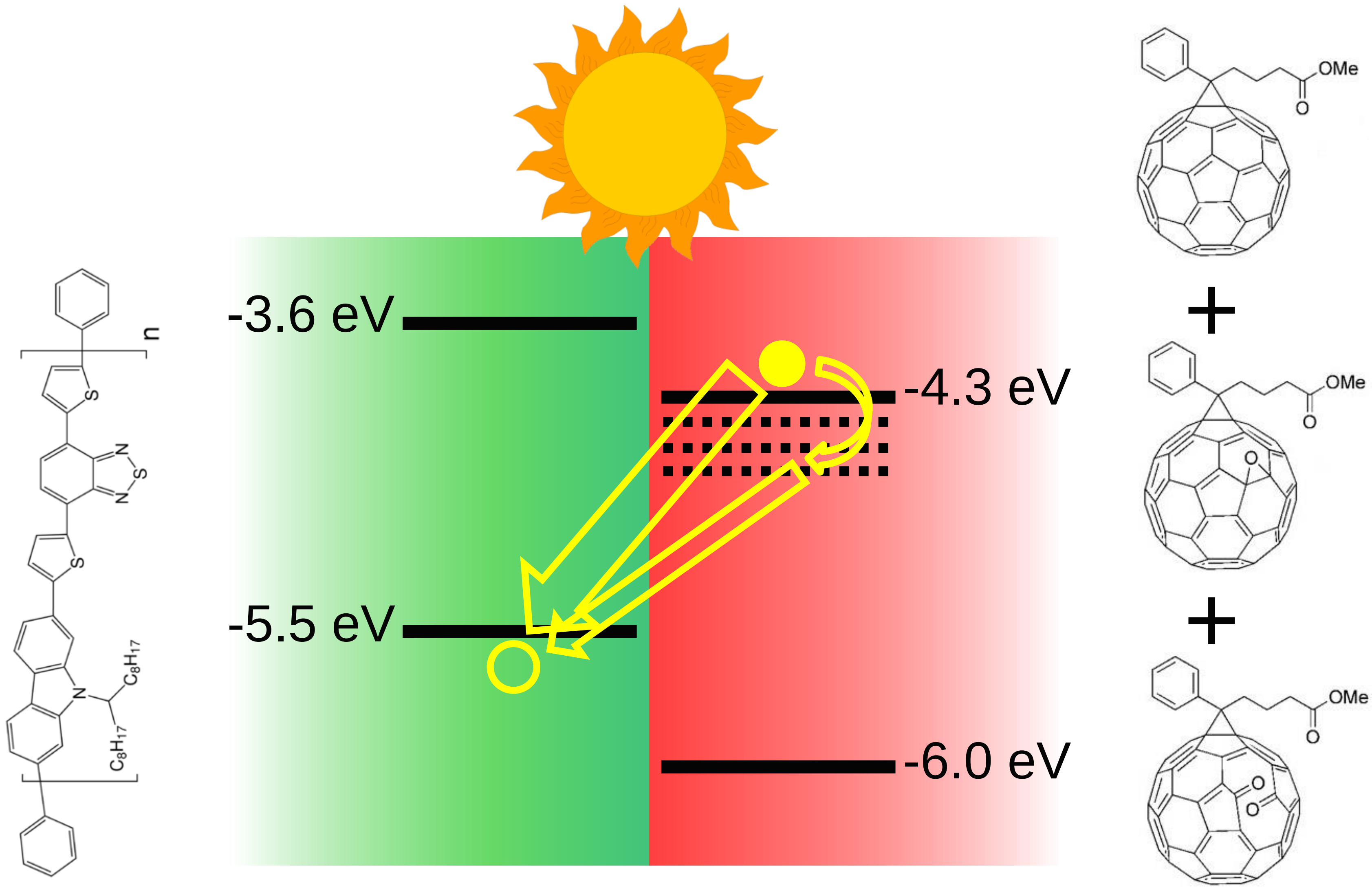
Sub-band gap states in PCBM



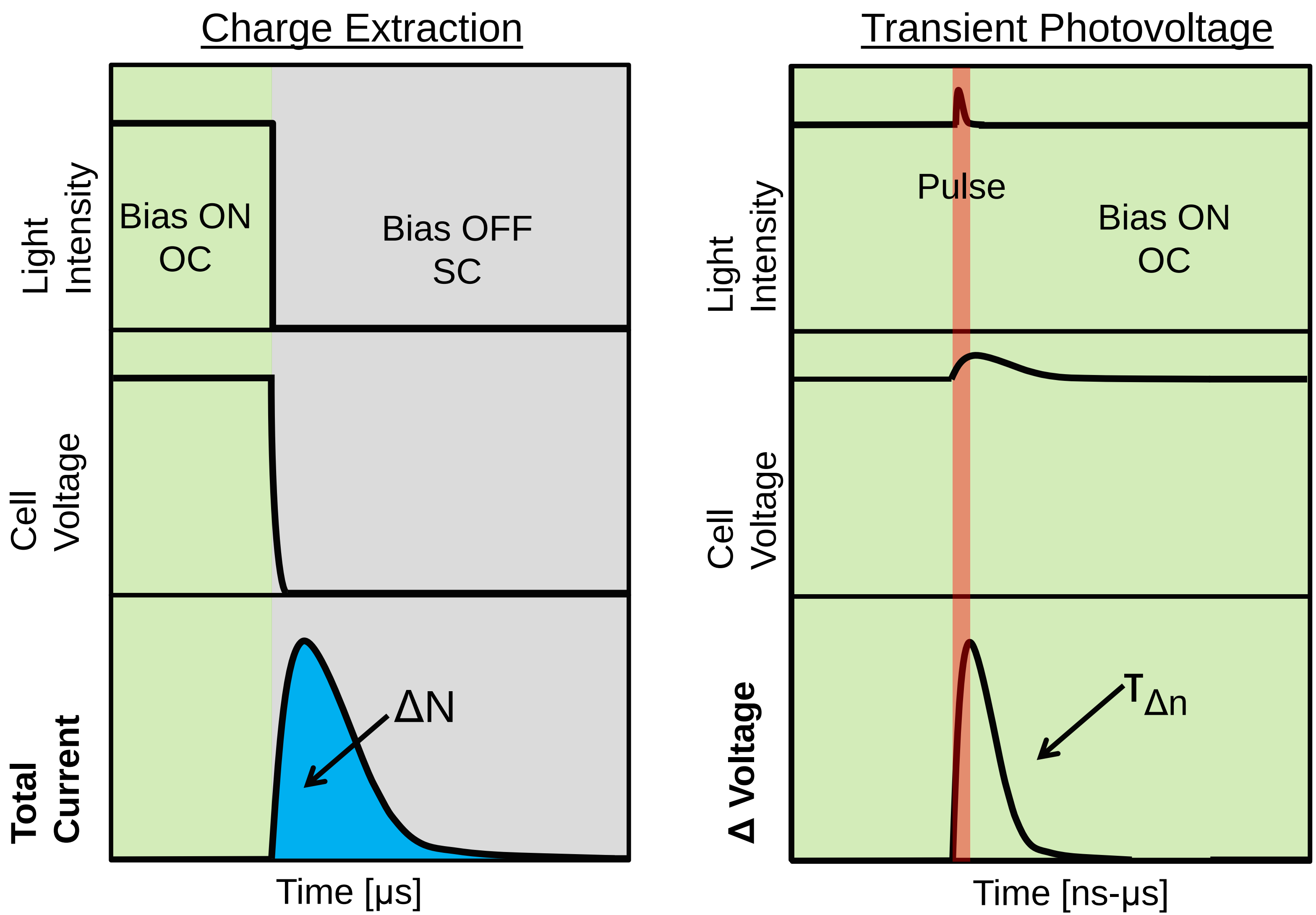




Effect on RECOMBINATION #1: solar cell



What happens in the device?



Charge extraction and Transient Photocurrent/Photovoltage Spectroscopies

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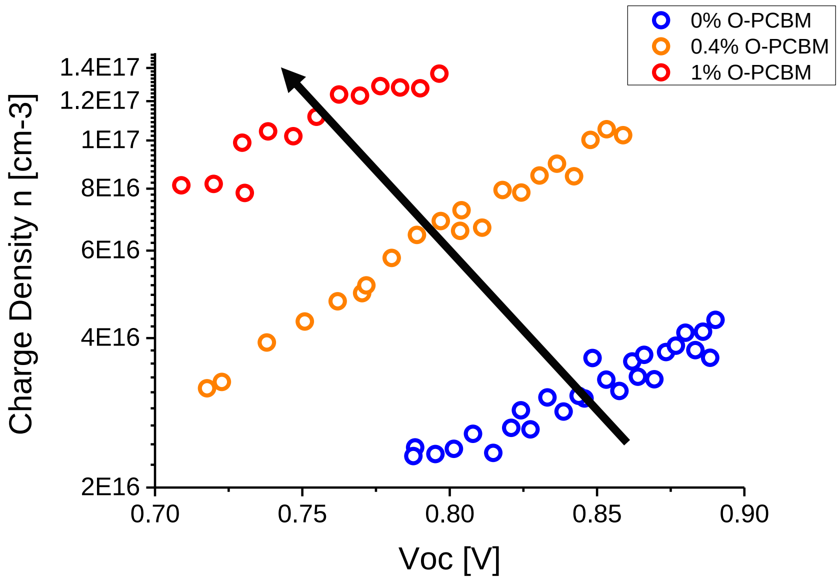
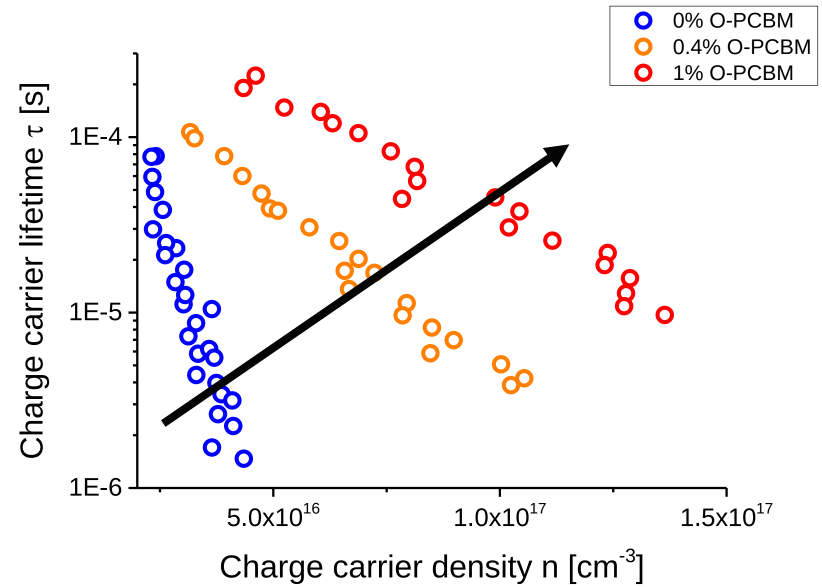
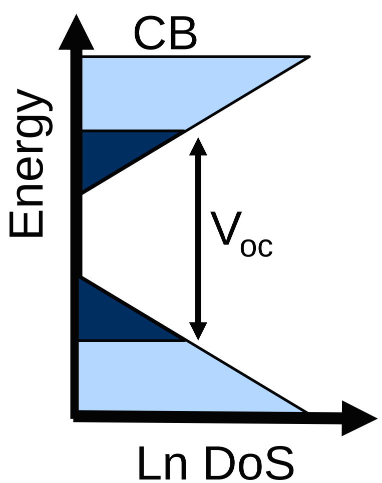
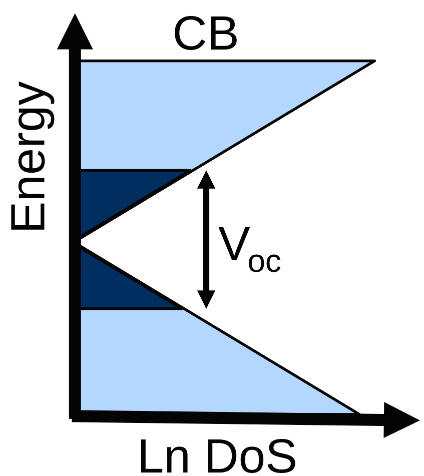
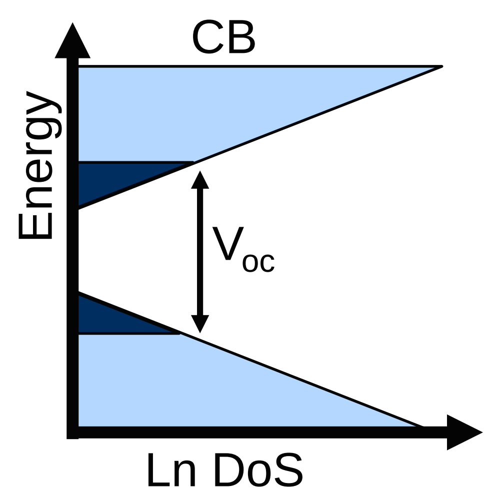
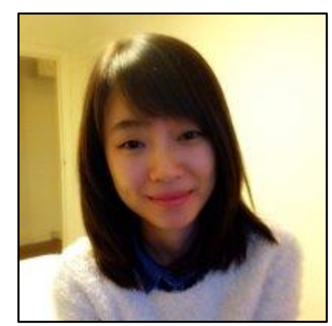






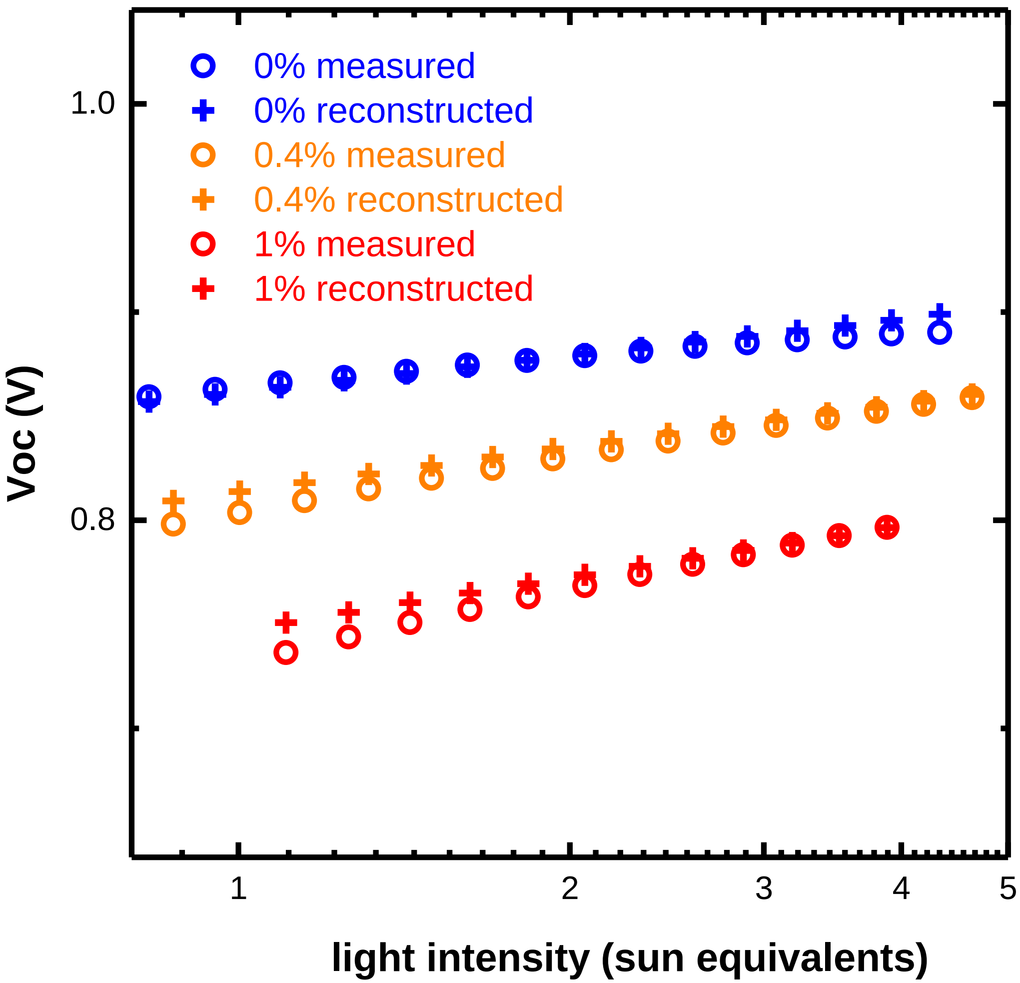




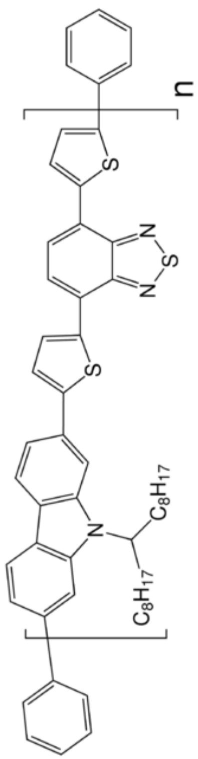


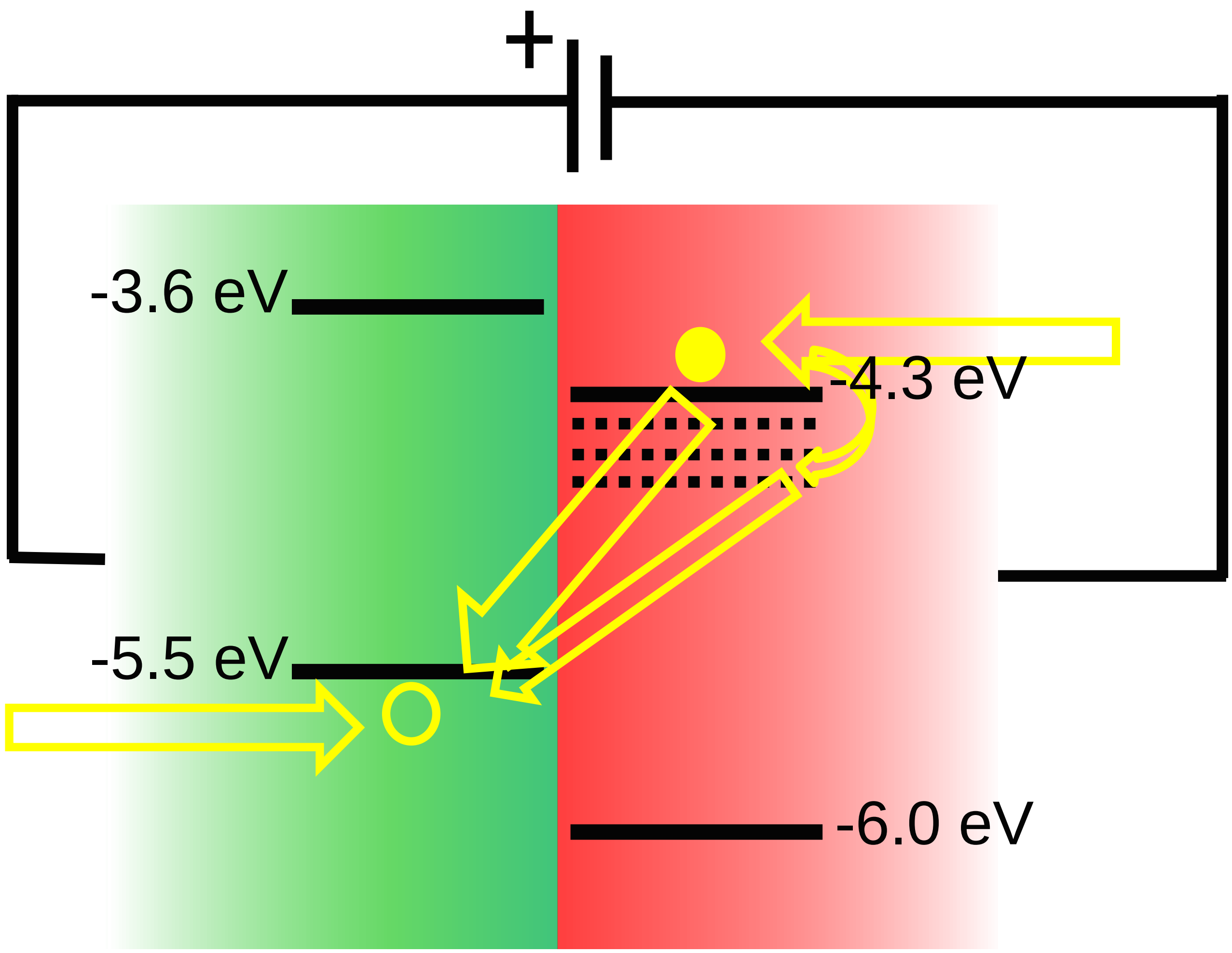
Jiaying Wu

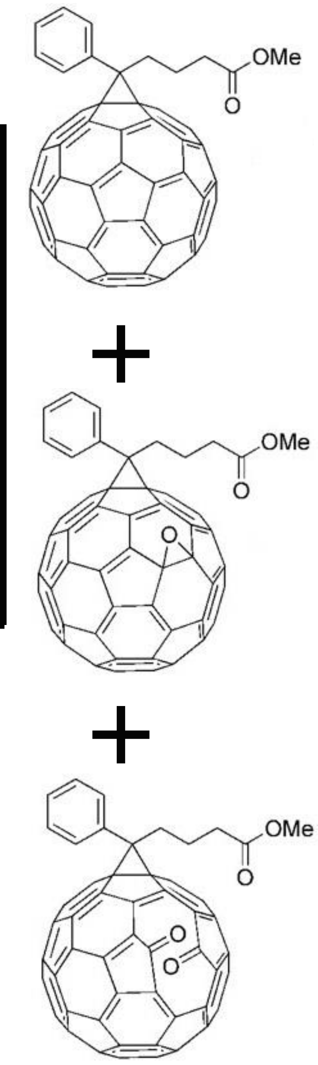
Voc reconstruction



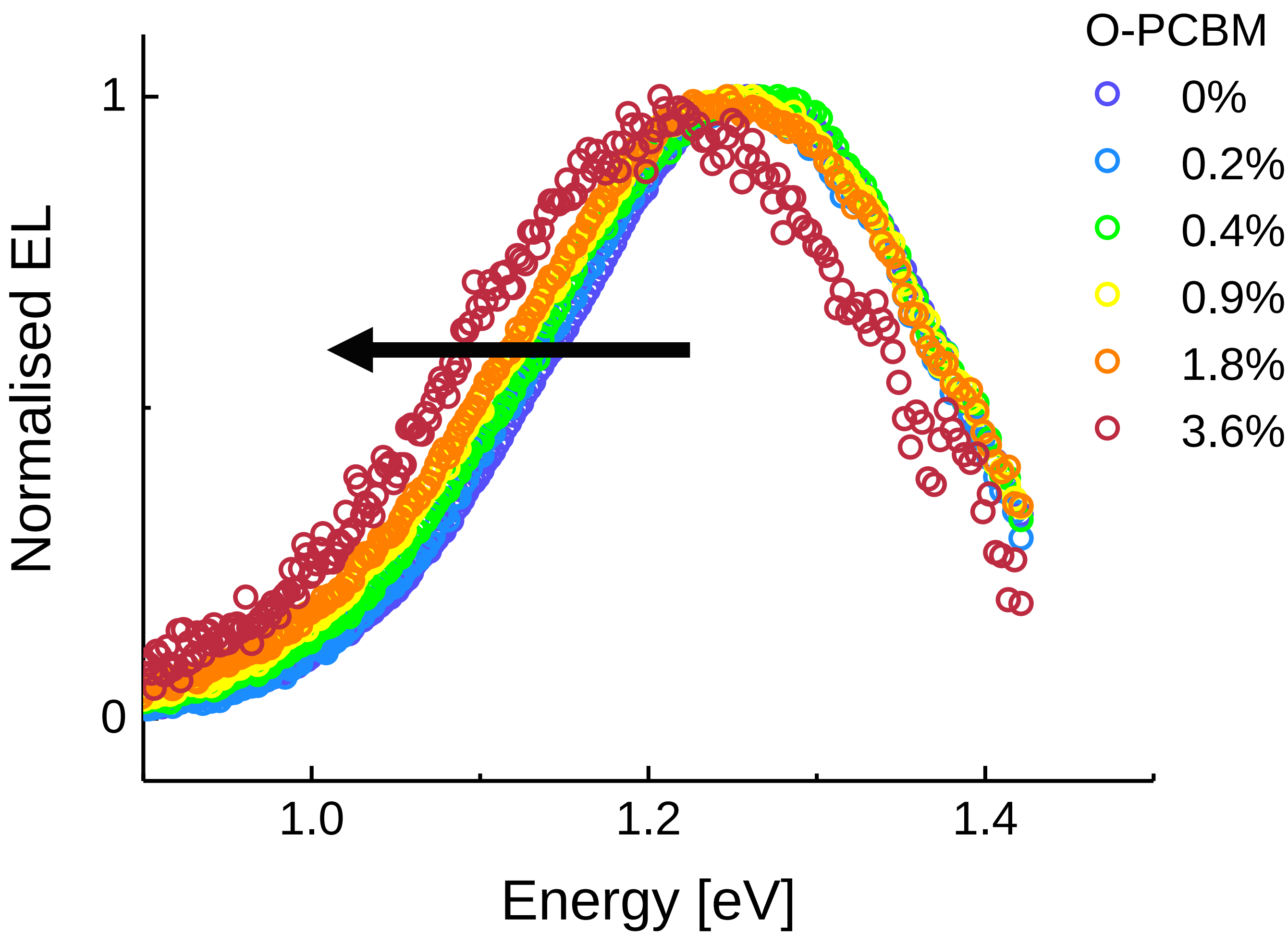
Effect on RECOMBINATION #2: LED





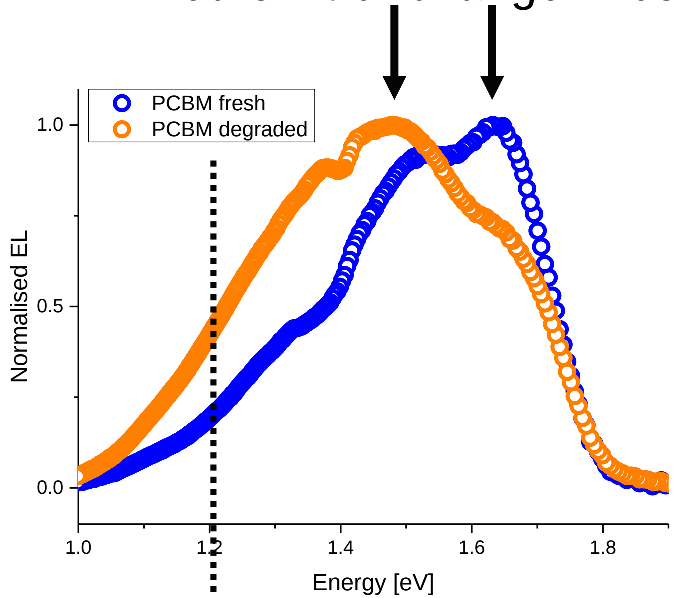


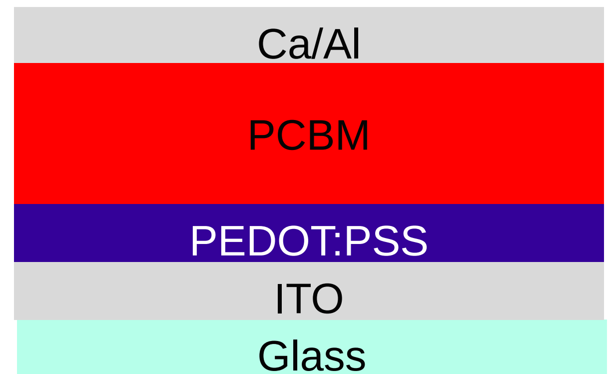
Electroluminescence

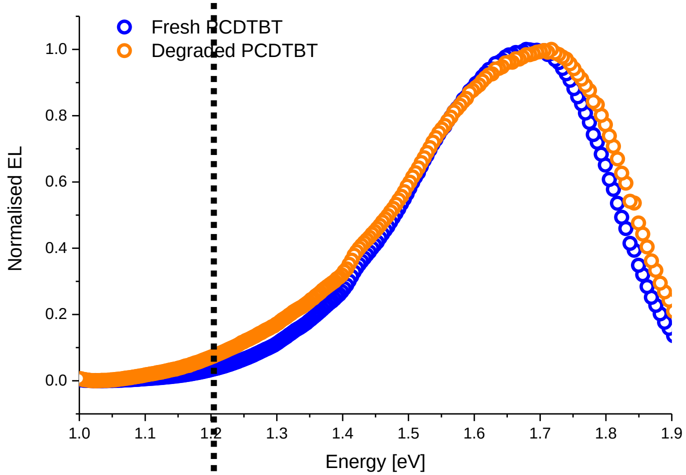


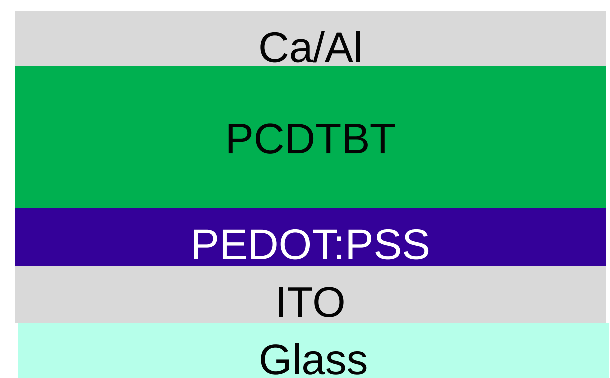
EL of pure blend components

Red-shift or change in oscillator strengths?

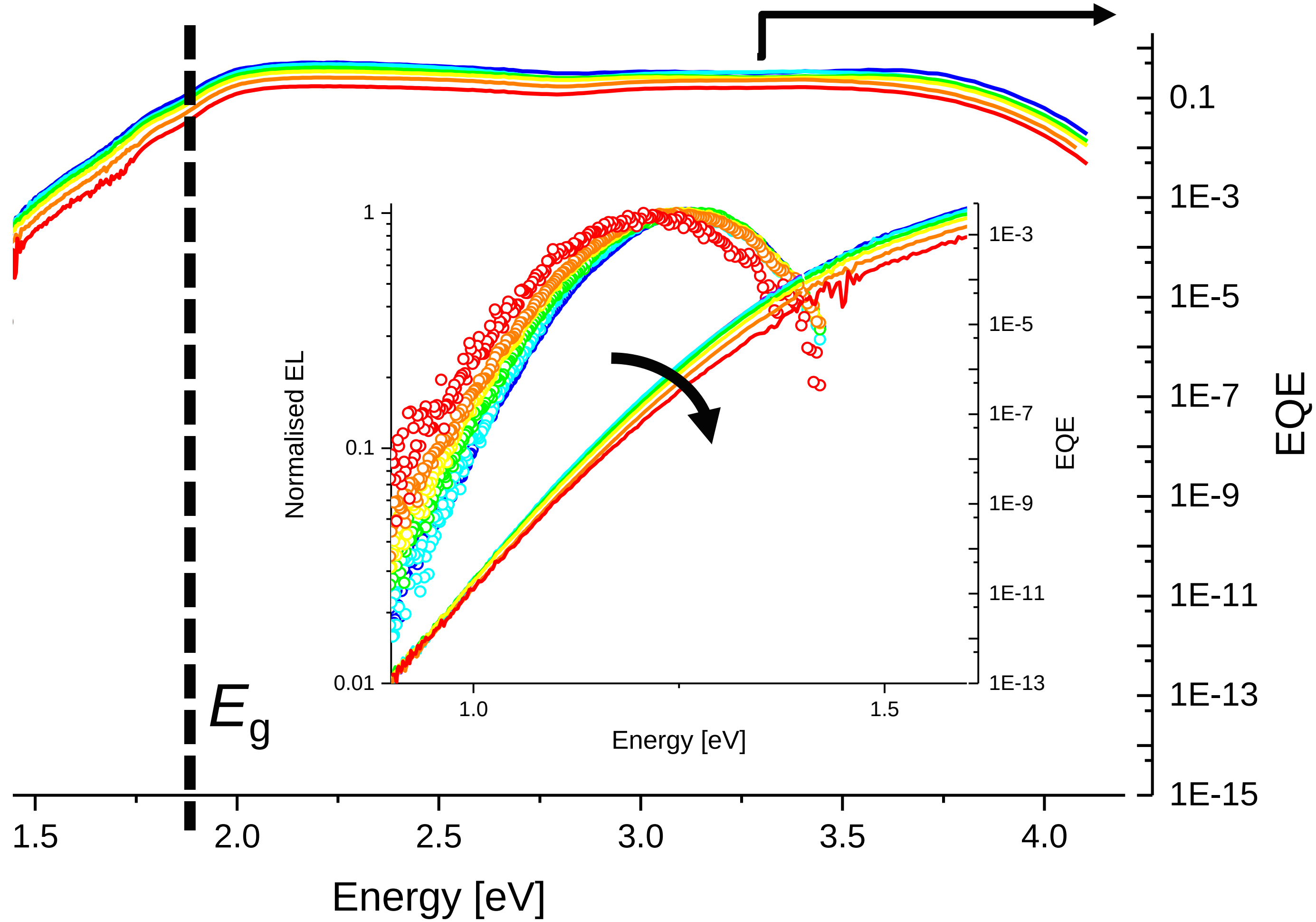






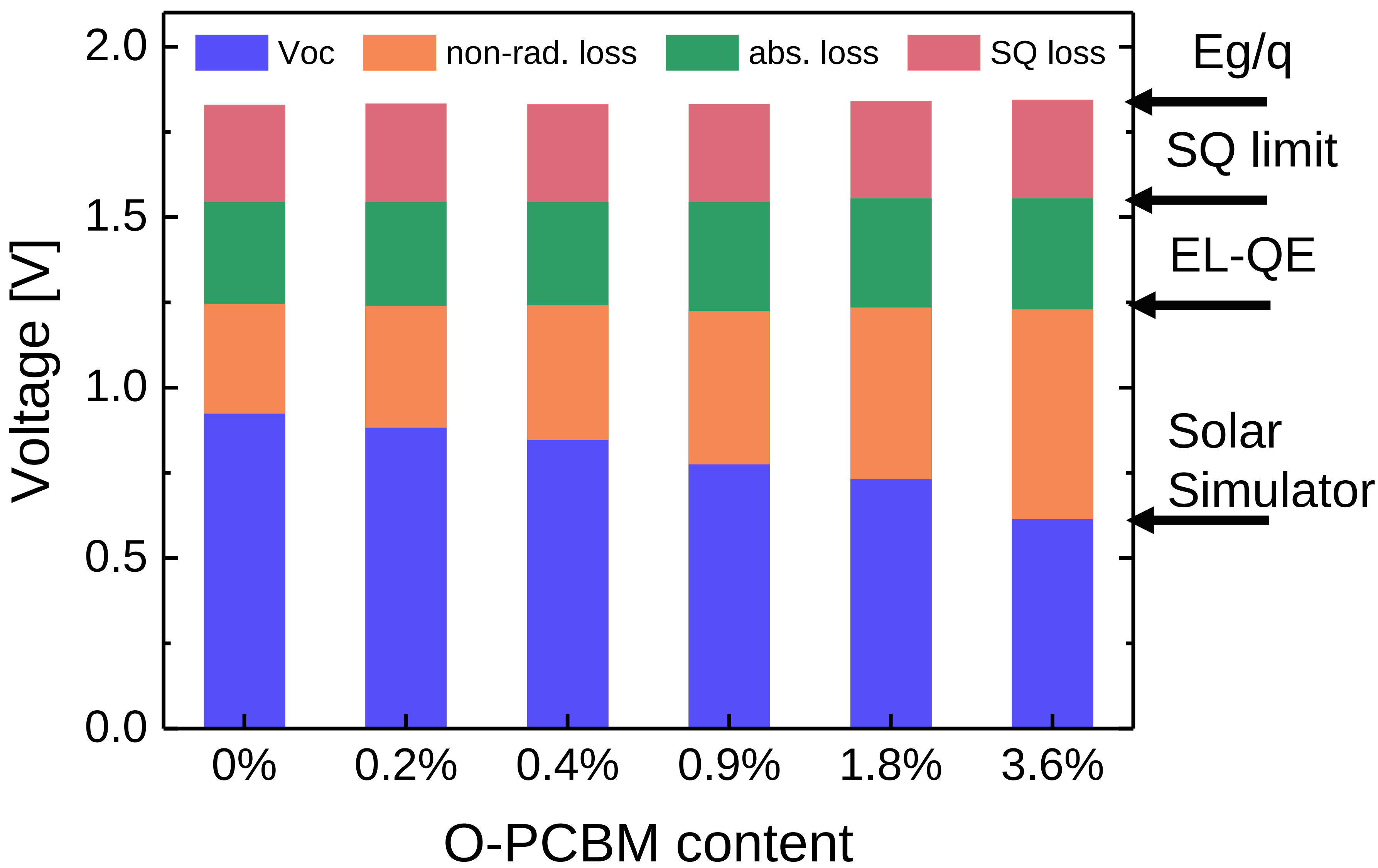


Electroluminescence and external quantum efficiency

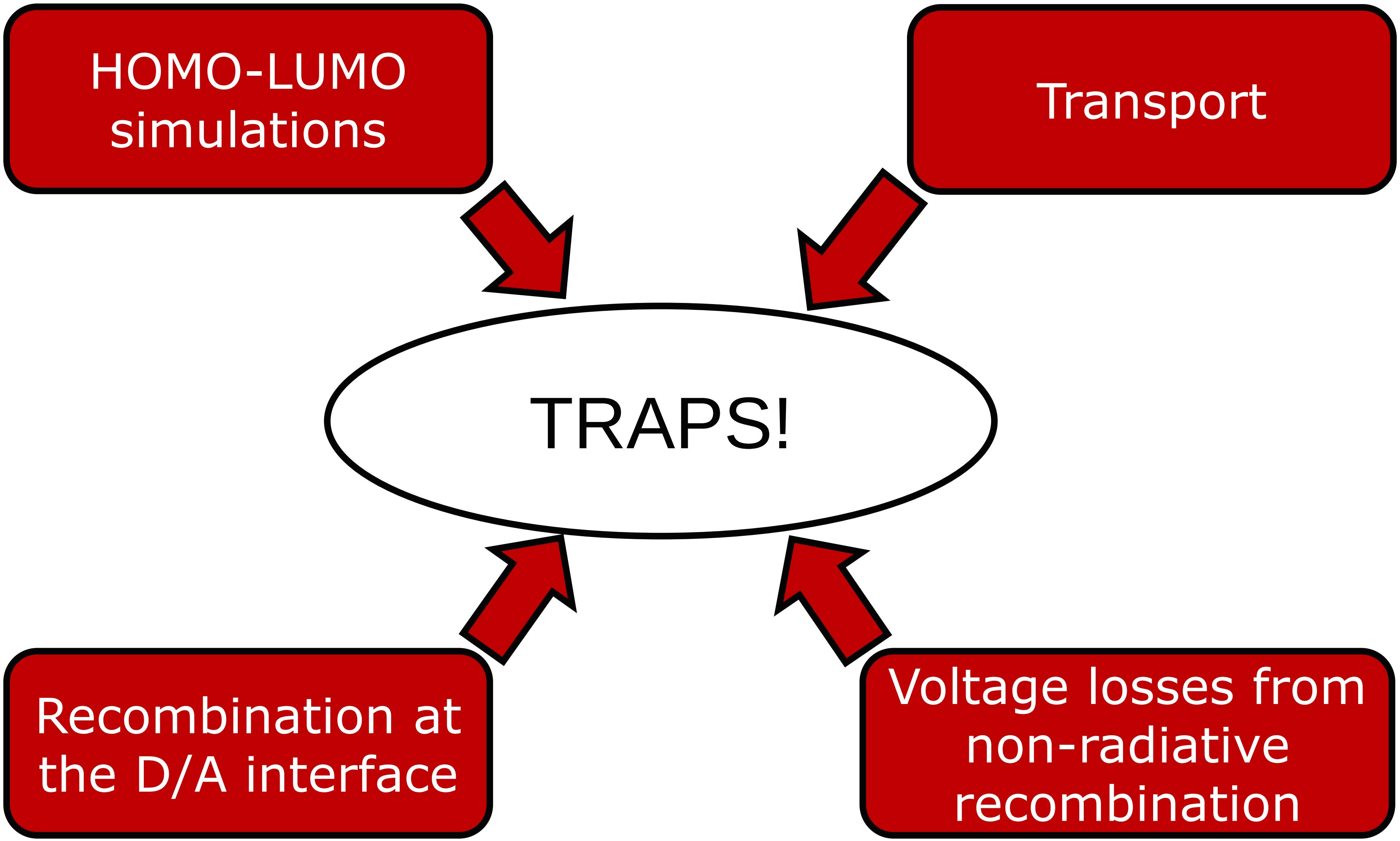


$$J_{0,rad} = q\int_0^\infty EQE \cdot \phi_{bb} dE \qquad V_{OC,rad} = \frac{kT}{q} ln\left(\frac{J_{sc,rad}}{J_{0,rad}} + 1\right)$$

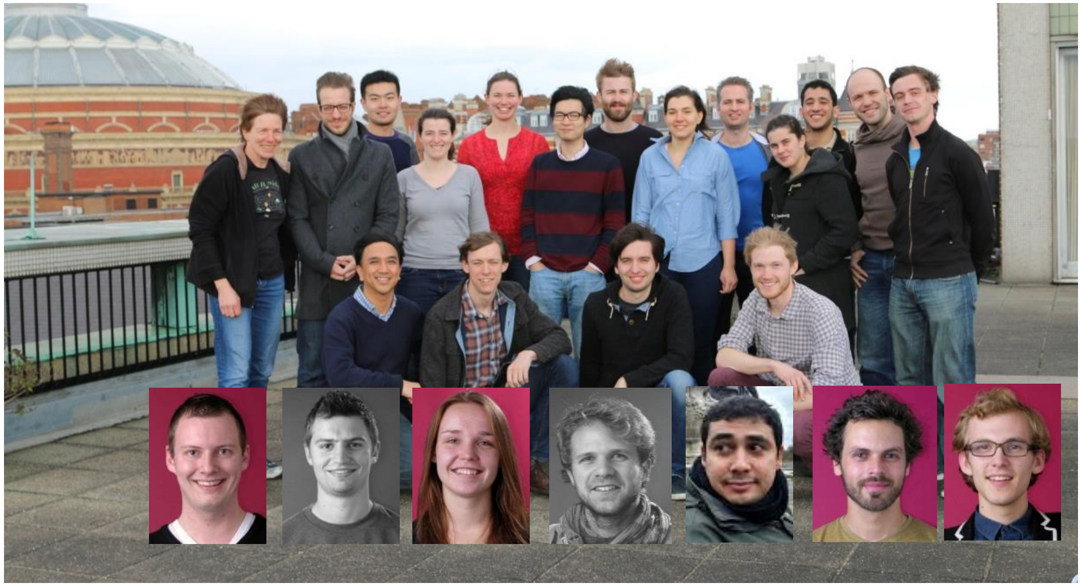
Open-circuit voltage losses



Conclusions



Thanks



- Piers Barnes (Imperial)
- James Durrant (Imperial)
- Dan Bryant (Imperial)
- Xiaoe Li (Imperial)
- Xuhua Wang (Imperial)
- Saif Haque (Imperial)
- Irene Sanchez (Imperial)
- Emily Speller (Swansea)
- Harrison K. H. Lee (Swansea)
- Emily Speller (Swansea)

- Wing C. Tsoi (Swansea)
- Zhe Li (Swansea)
- Matt Carnie (Swansea)
- Joel Troughton (Swansea)
- Josep Sancho (Valencia)
- Brian Saunders (Manchester)
- Paul O'Brien (Manchester)
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