HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

JÜLICH Forschungszentrum

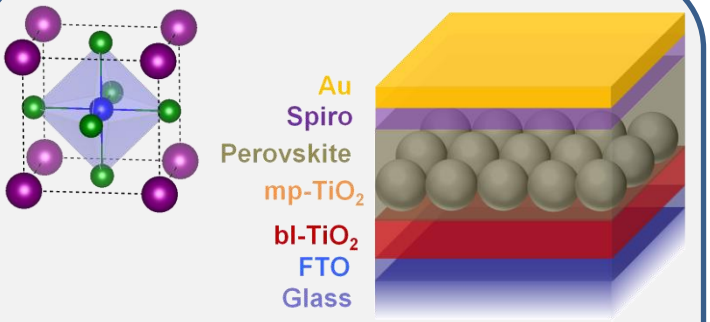
Current developments and perspectives for polymer-based and metal-halide perovskite solar cells

Thomas Kirchartz
IEK-5 Photovoltaik, Forschungszentrum Jülich
NST and CENIDE, Universität Duisburg-Essen

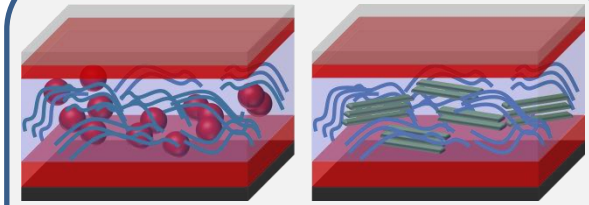
Outline

Perovskite based solar cells

- Defects (Recombination, Metastabilities)
- Degradation
- Contacts



ABX_3 Solar Cells

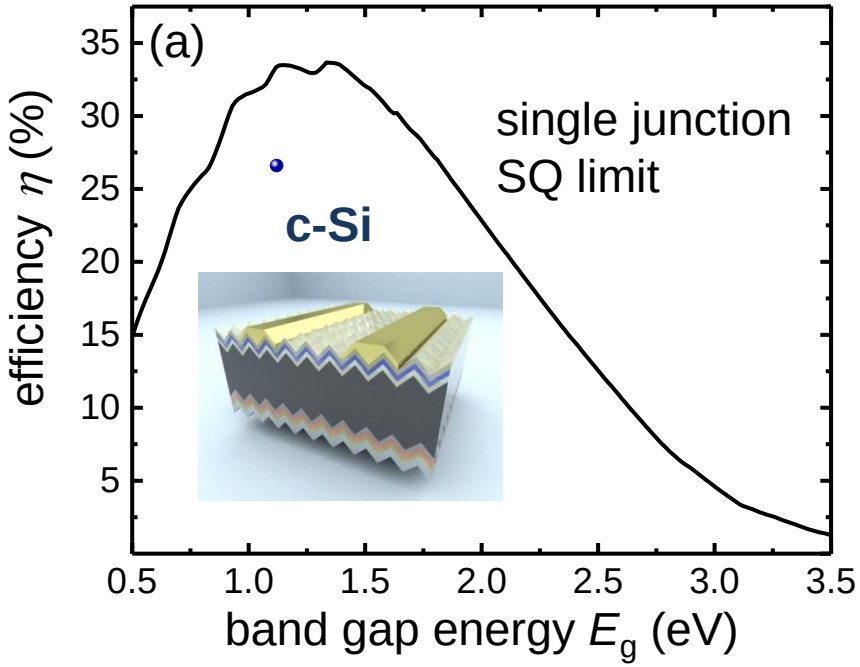


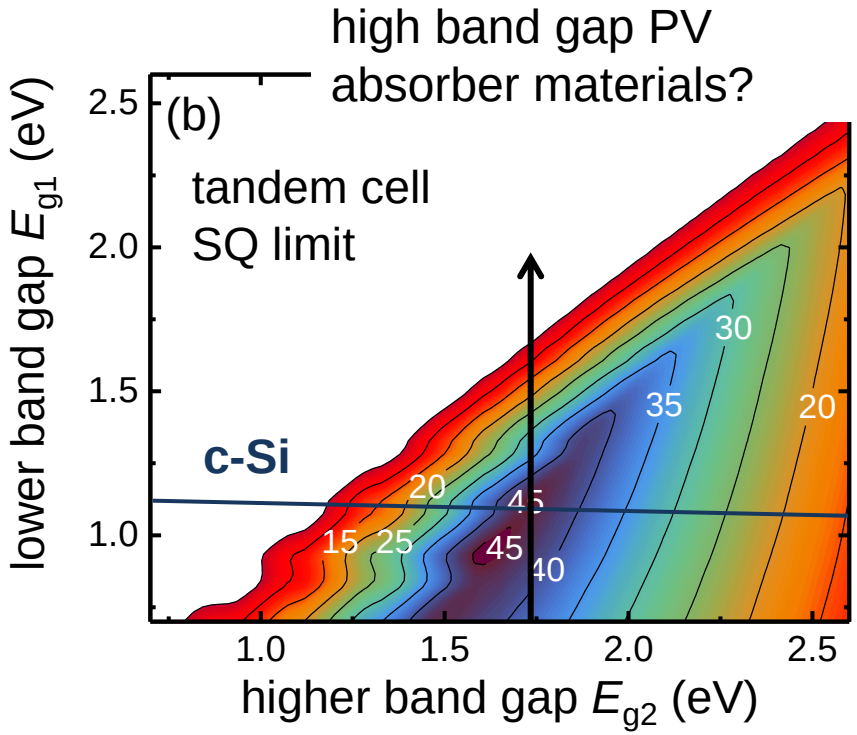
Organic Solar Cells

Organic solar cells

- Acceptor molecules
- Charge collection

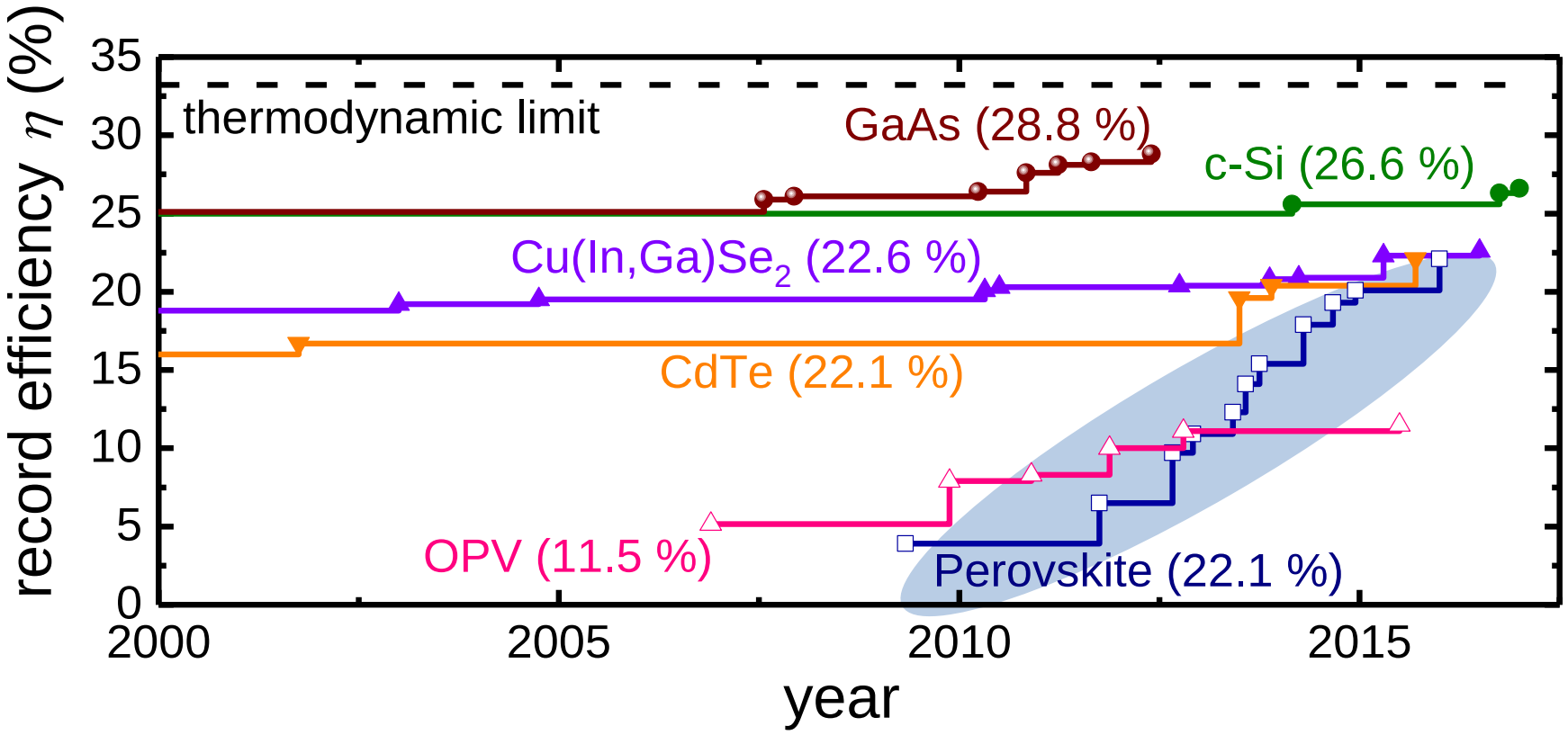
Shockley-Queisser Limit





Recent Trends in Solution Processable PV

Efficiency Increase of Perovskite Solar Cells



Recent Trends in Solution Processable PV

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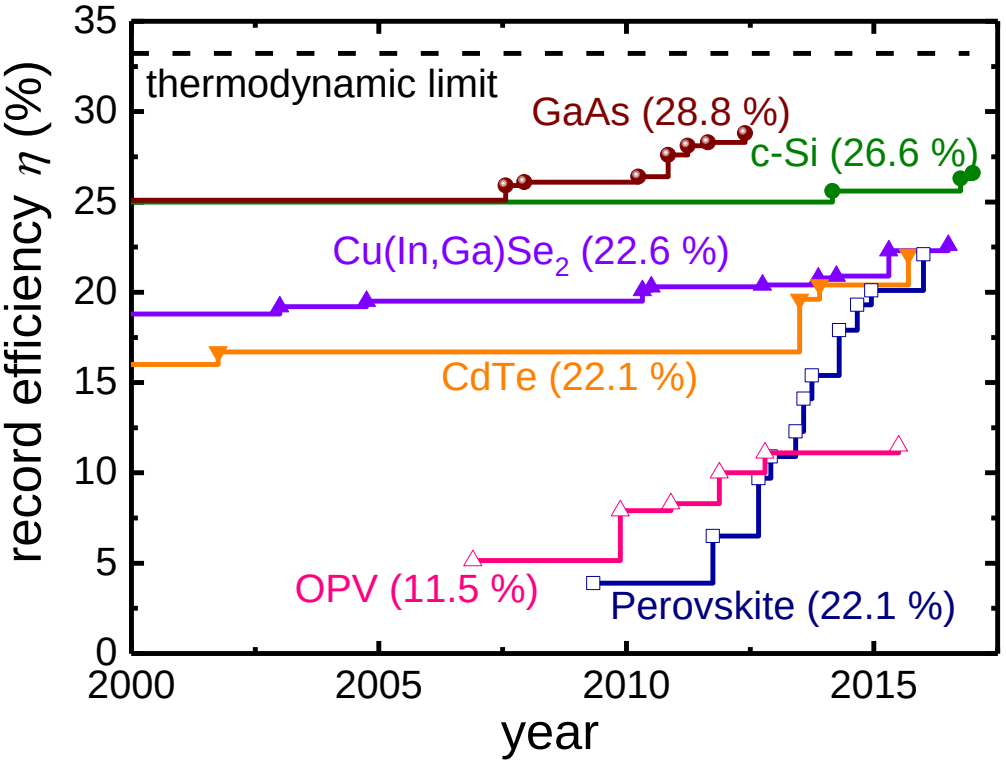
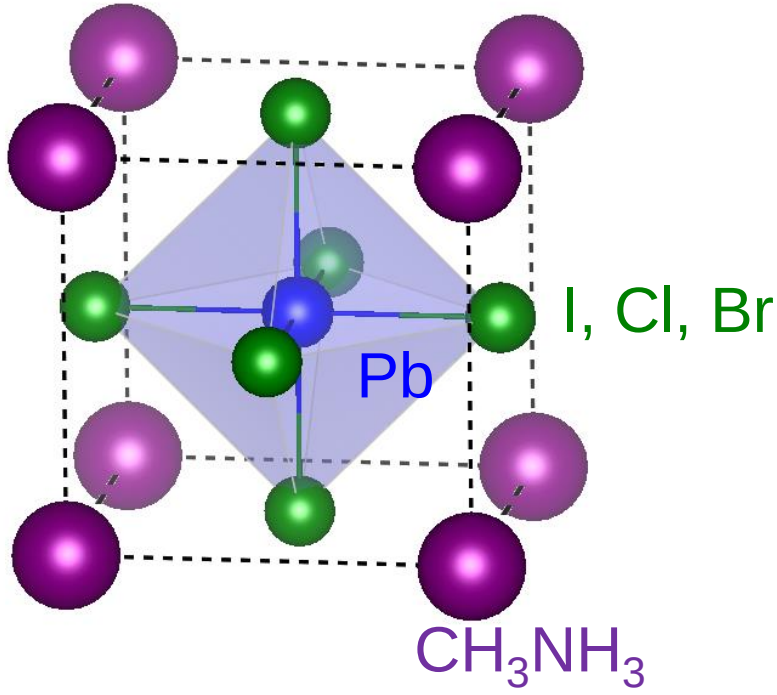
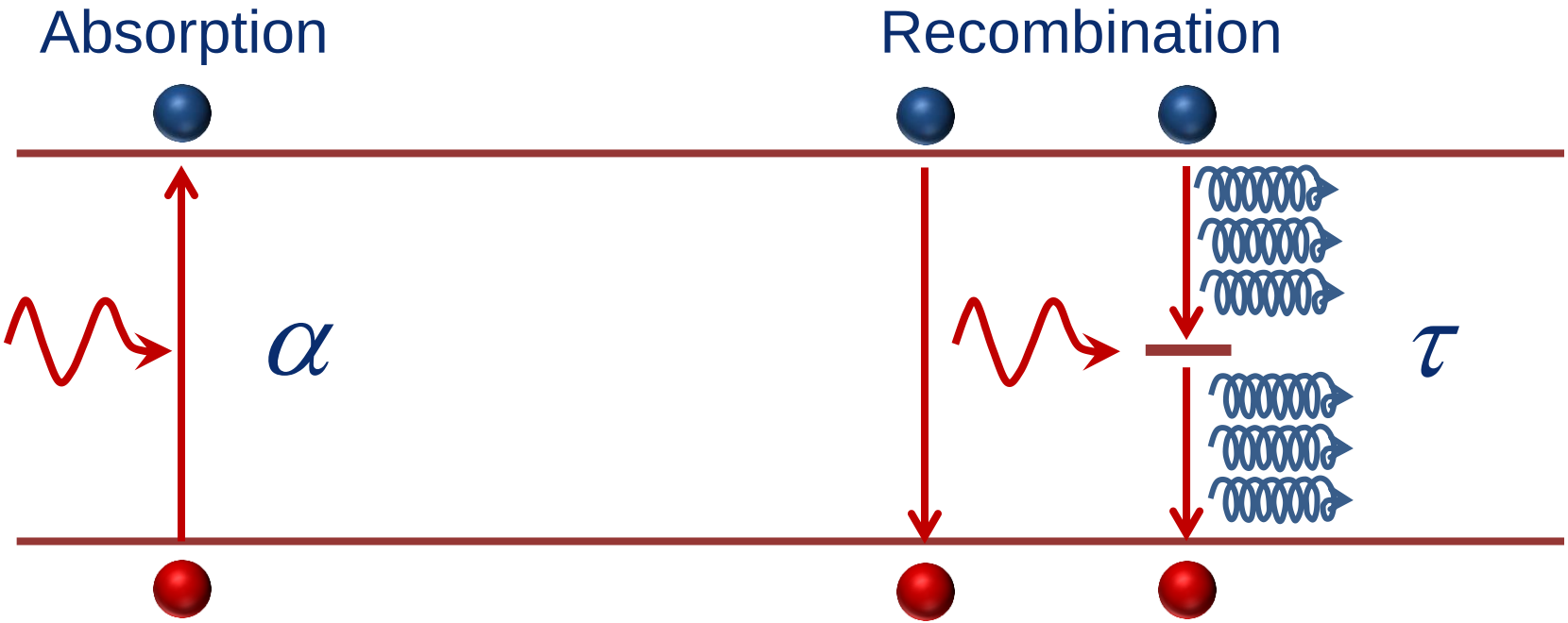


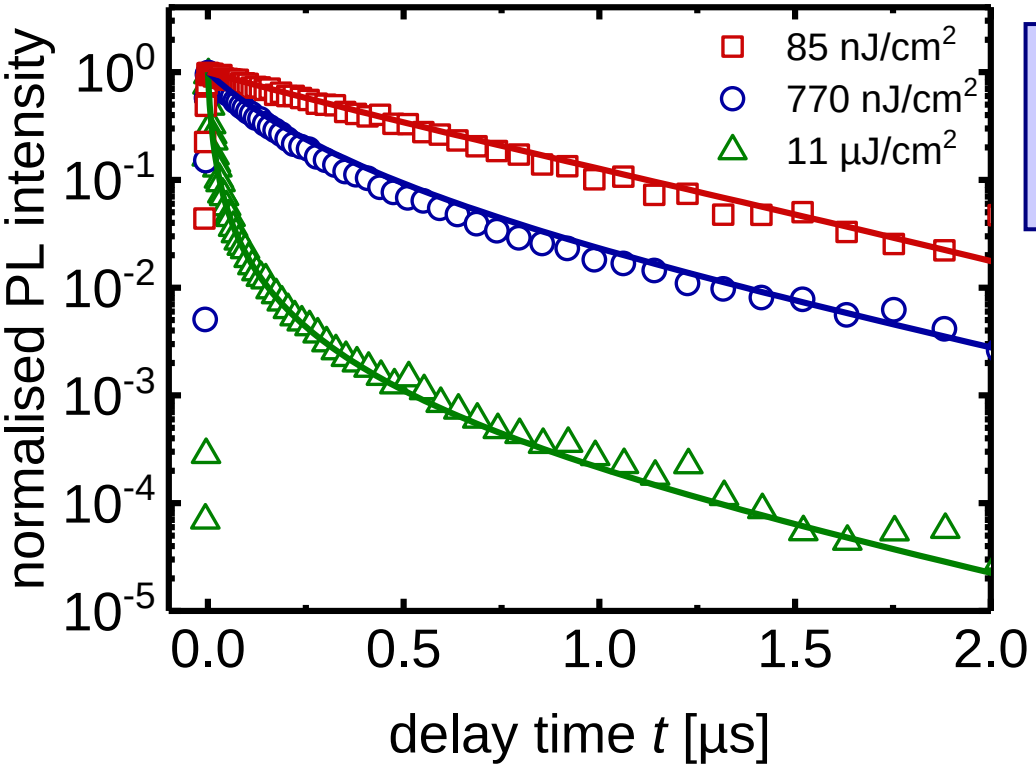


Requirements for a Good Solar Cell



Electron-photon coupling should be faster than electron-phonon coupling!

Transient Photoluminescence of $CH_3NH_3PbI_3$ Films on Glass



$$-\frac{dn}{dt} = \frac{n}{\tau} + k^* n^2 + Cn^3$$

Staub et al. Phys. Rev. Appl. **6**, 044017 (2016)

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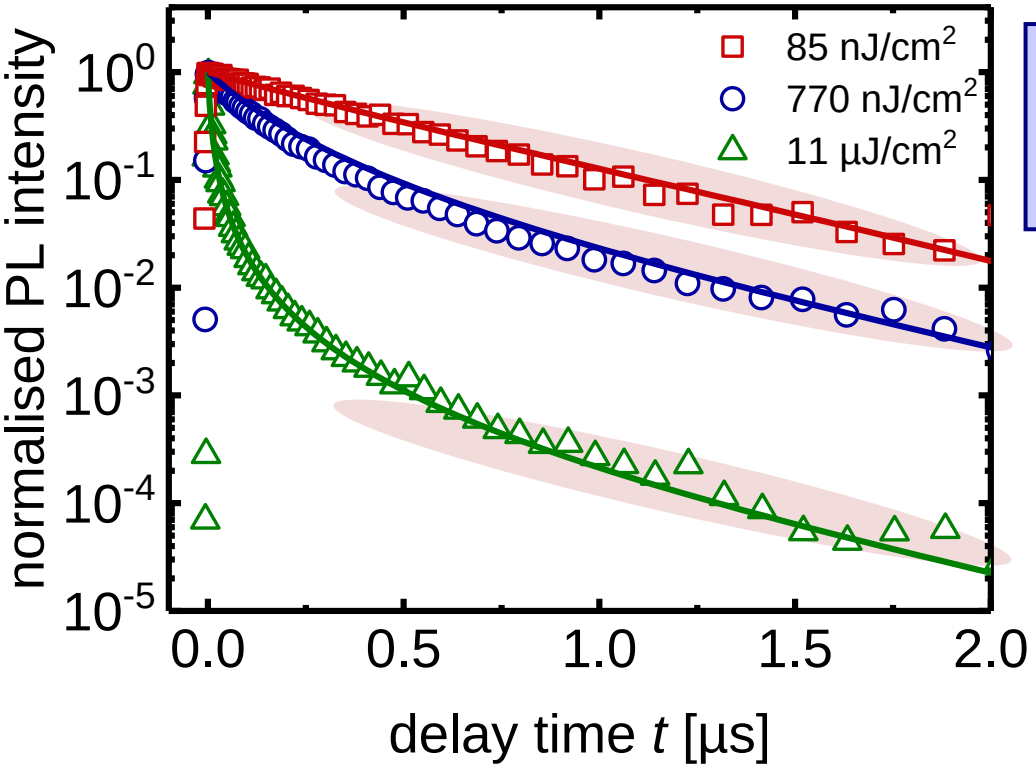


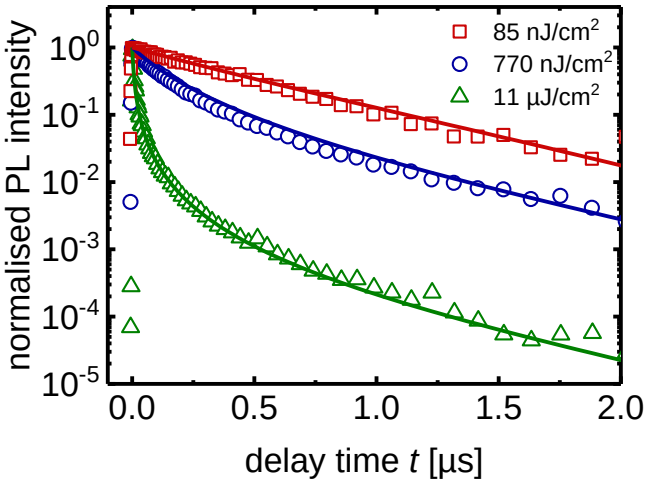
$$-\frac{dn}{dt} = \frac{n}{\tau} + k^* n^2 + Cn^3$$

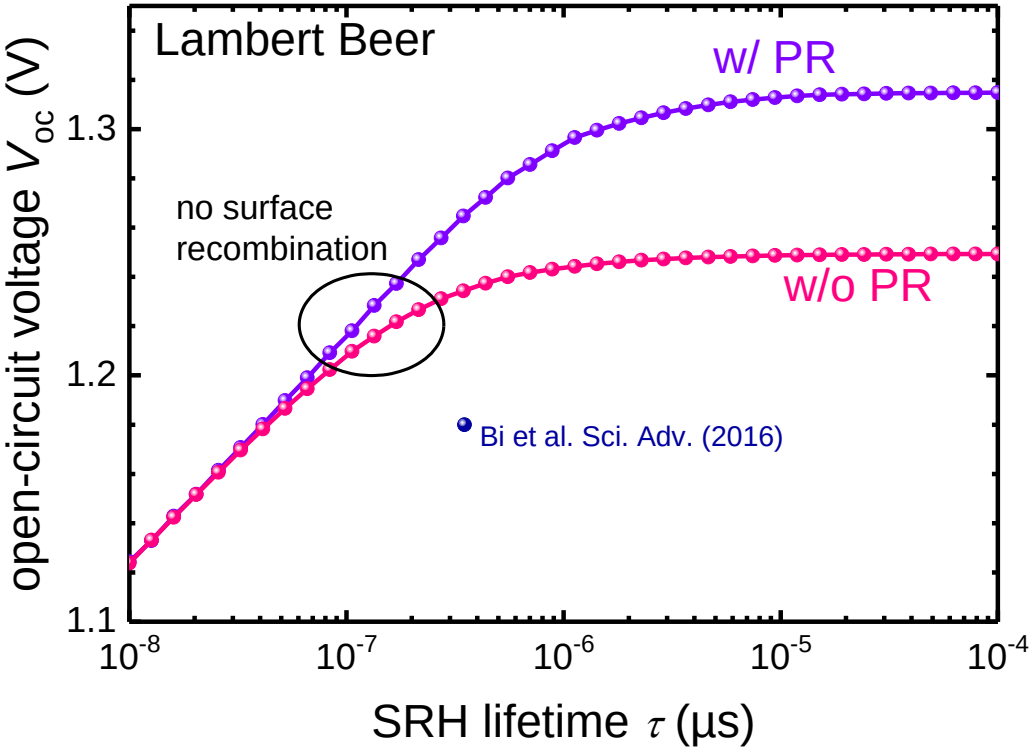
Lifetime $\tau \sim 500$ ns
extremely long for
polycrystalline semiconductors

Staub et al. Phys. Rev. Appl. **6**, 044017 (2016)

Effect of Lifetime on V_{oc}

Including Photon Recycling

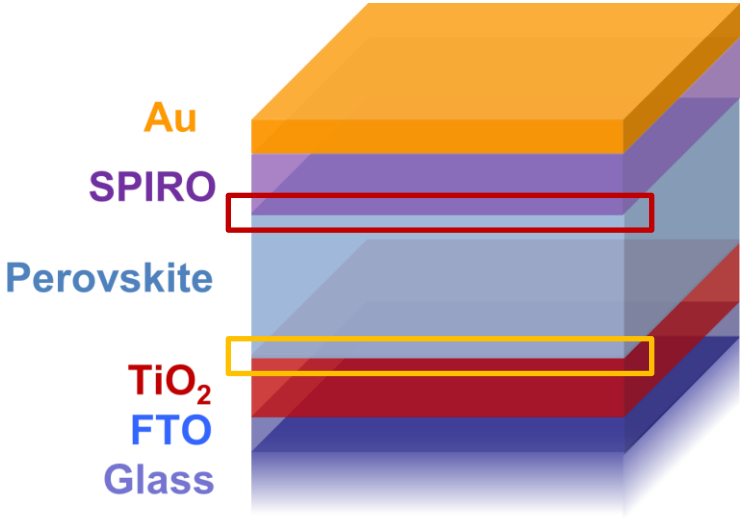


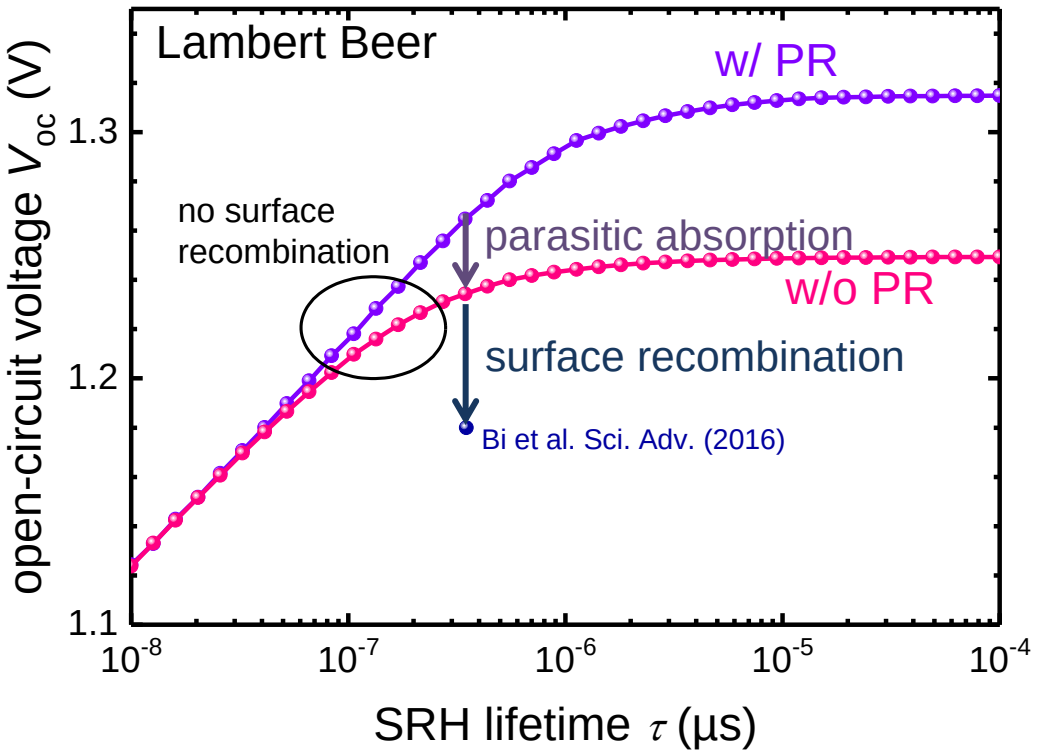


Kirchartz et al. ACS Energy Lett. **6**, 044017 (2016)

Effect of Lifetime on V_{oc}

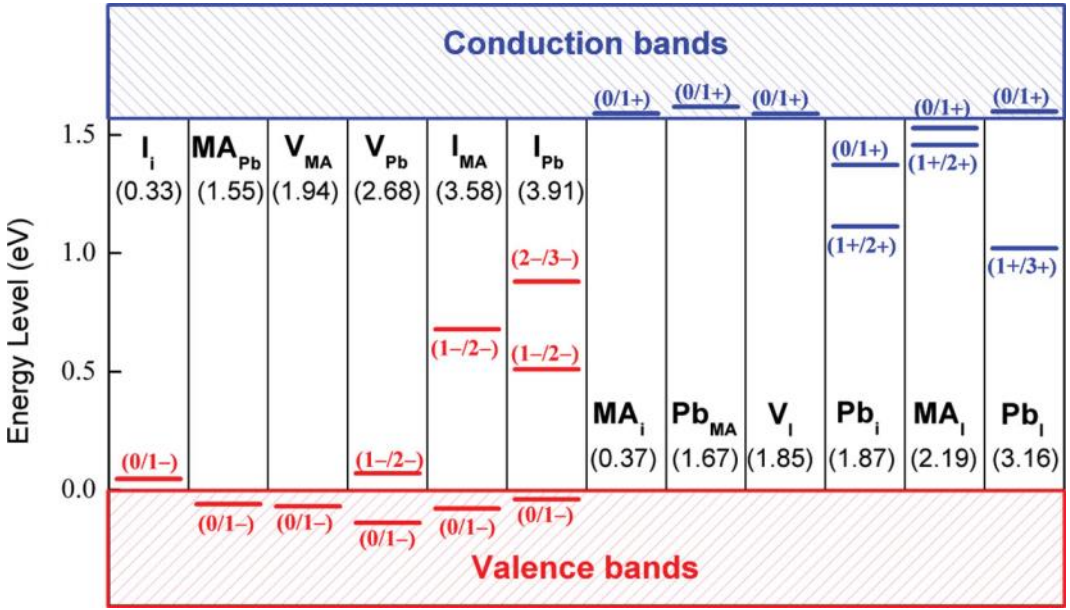
Contact Recombination

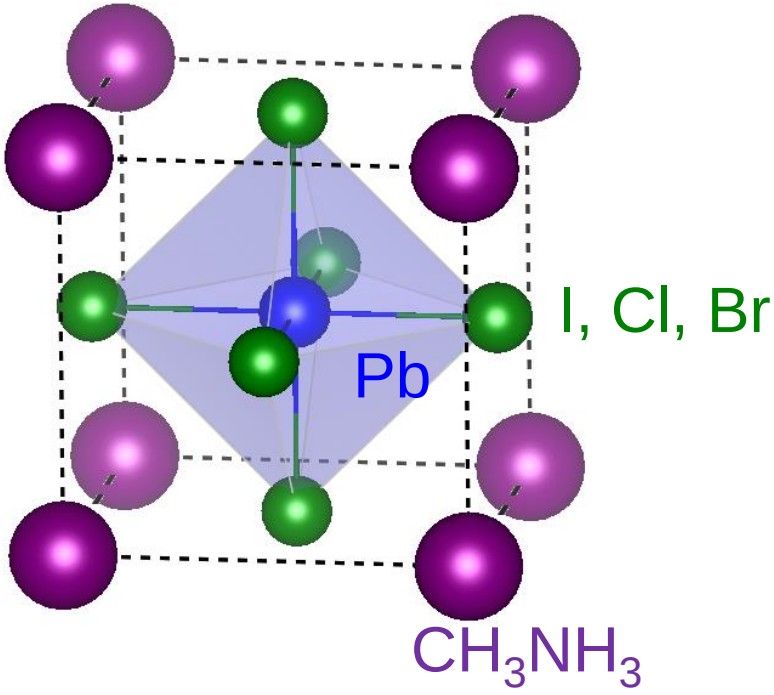




Lead-Halide Perovskites

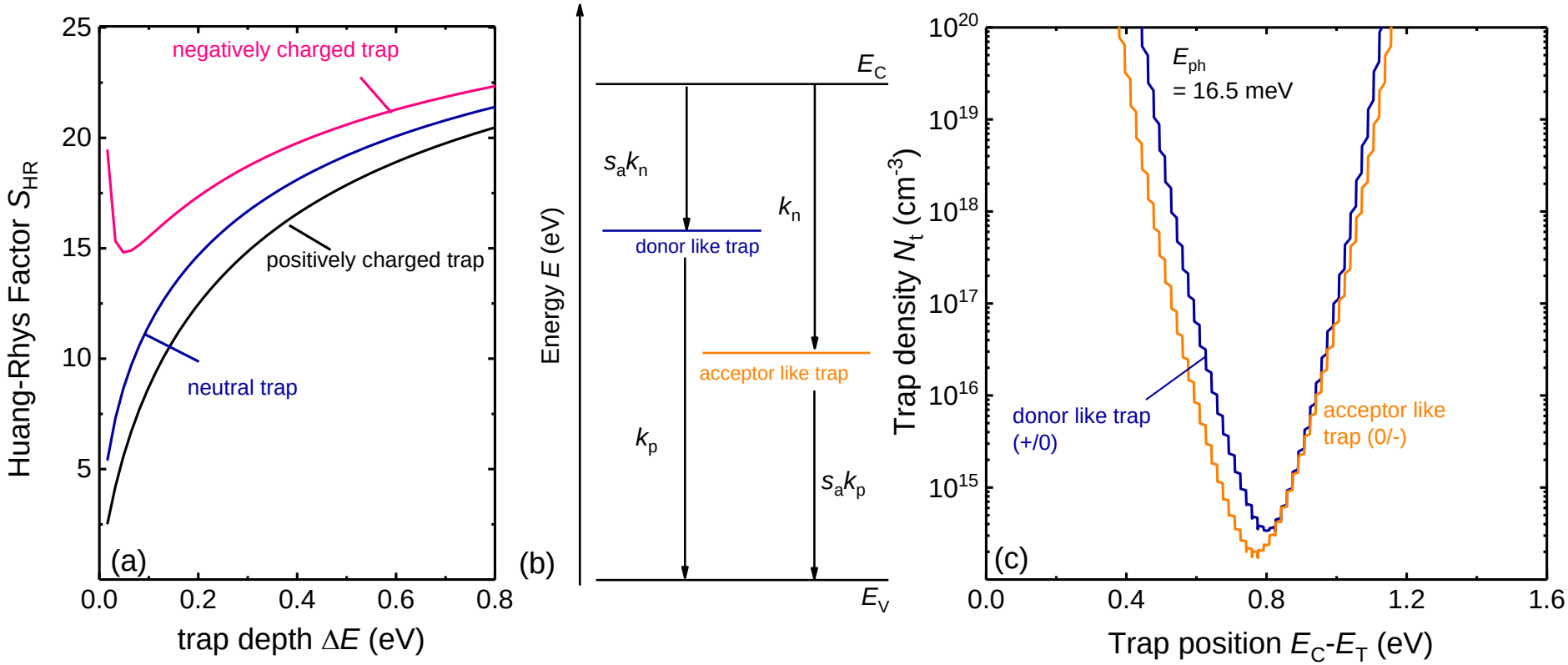
Long Lifetimes due to Low Densities of Deep Defects





Yin et al., Appl. Phys. Lett. **104**, 063903 (2014)

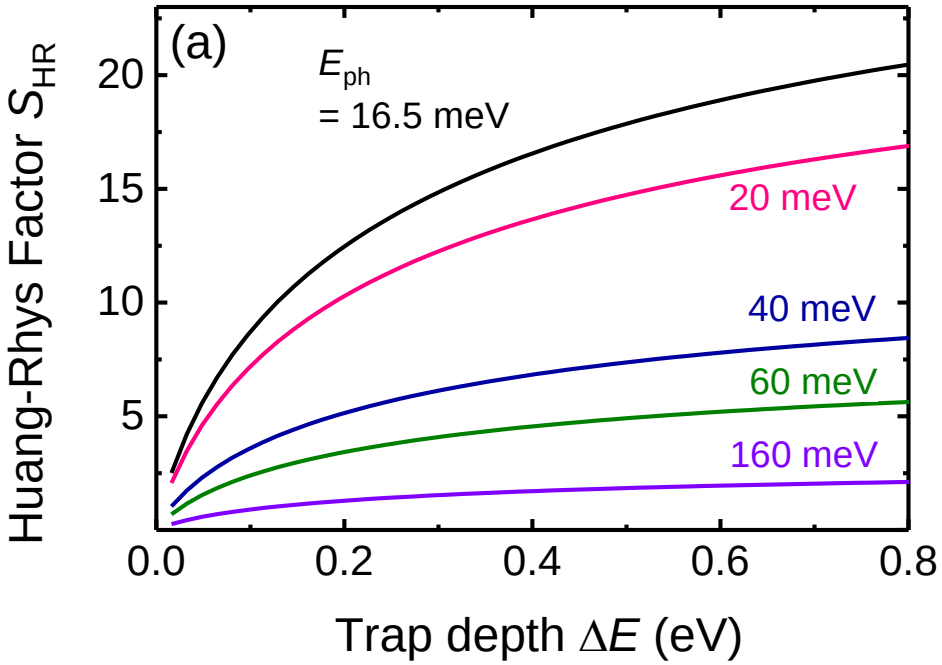
Multiphonon Recombination

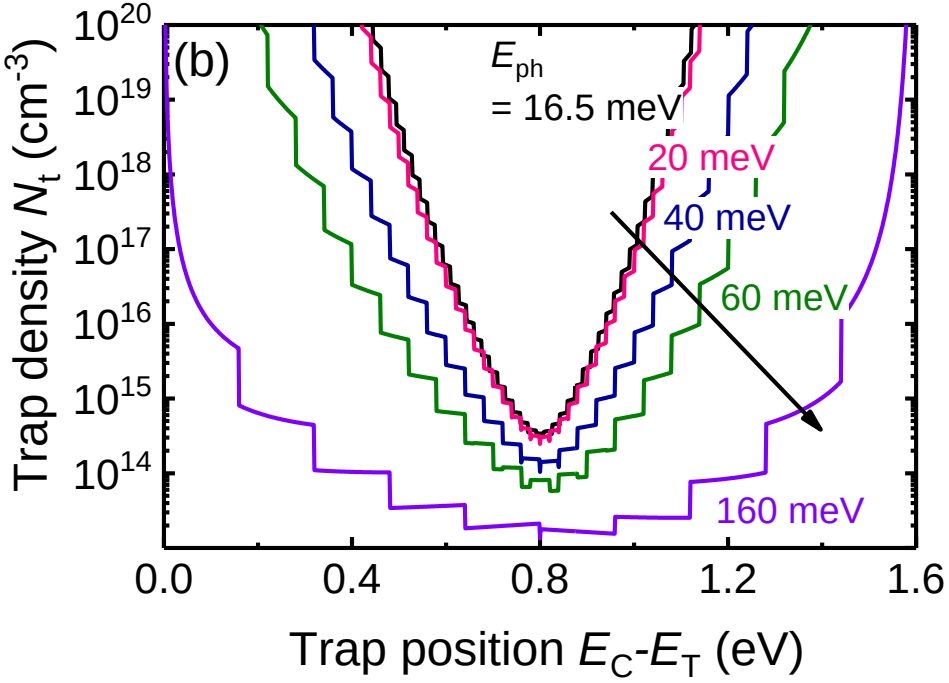


Kirchartz et al., J. Phys. Chem Lett. **9**, 939 (2018)

Multiphonon Recombination

Benefits of low phonon energies in polar semiconductors

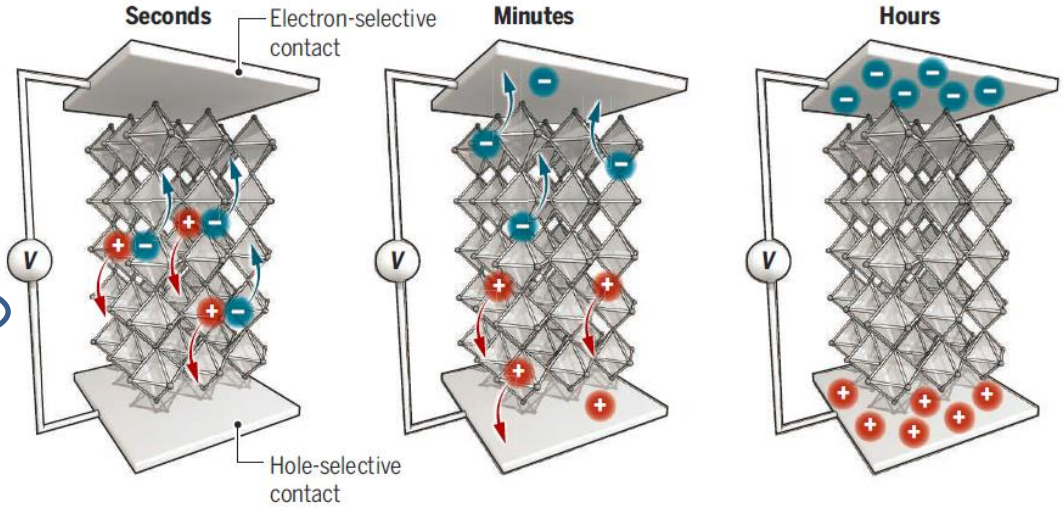




Kirchartz et al., J. Phys. Chem Lett. **9**, 939 (2018)

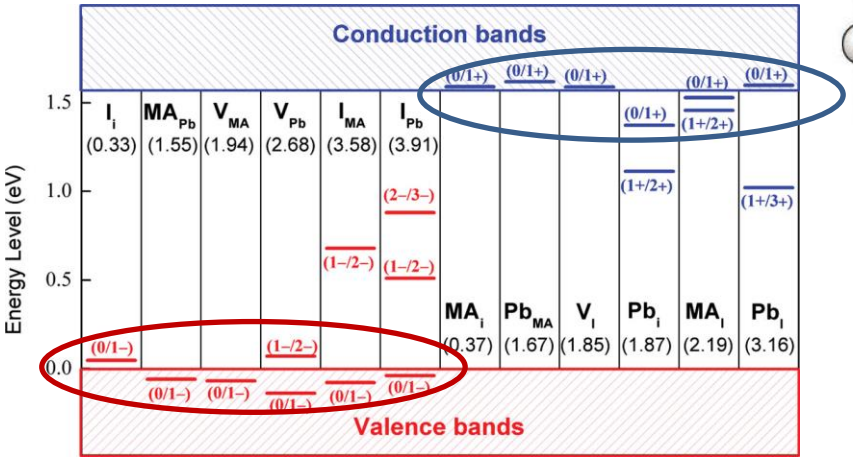
Transient Effects

Ion Movement



Saliba, Science **359**, 388 (2018)

Shallow donors

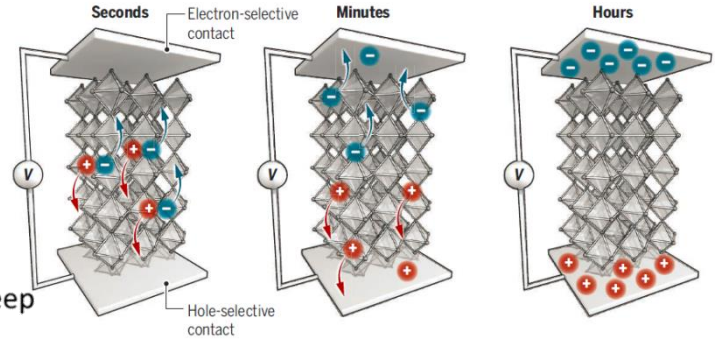


Shallow acceptors

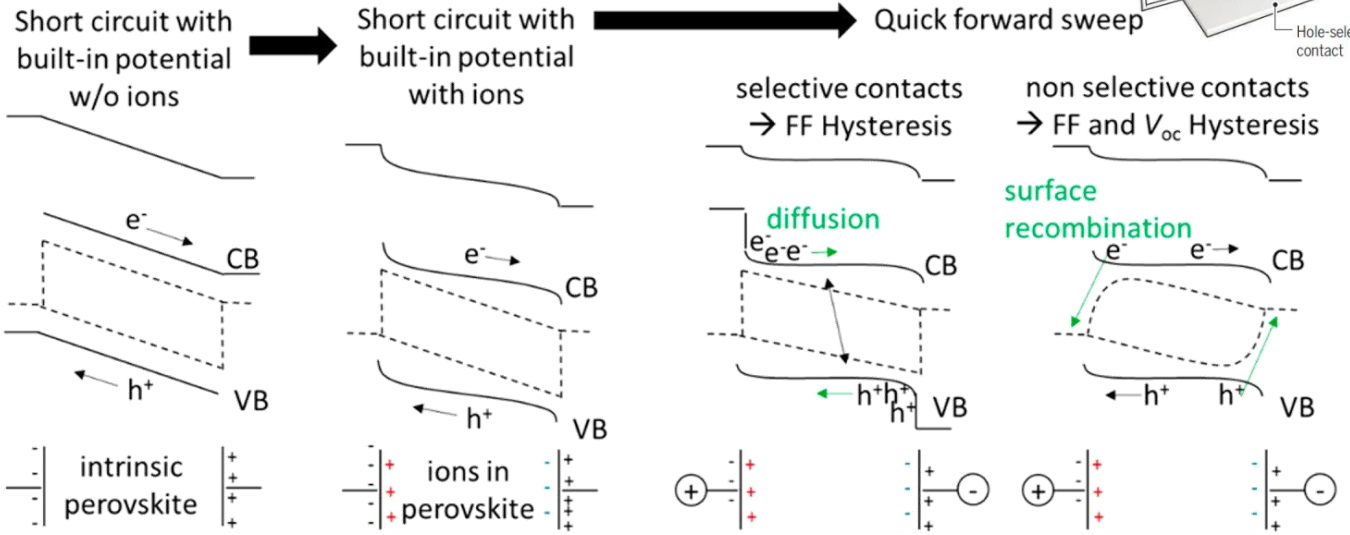
Yin et al., Appl. Phys. Lett. **104**, 063903 (2014)

Transient Effects

Ion Movement



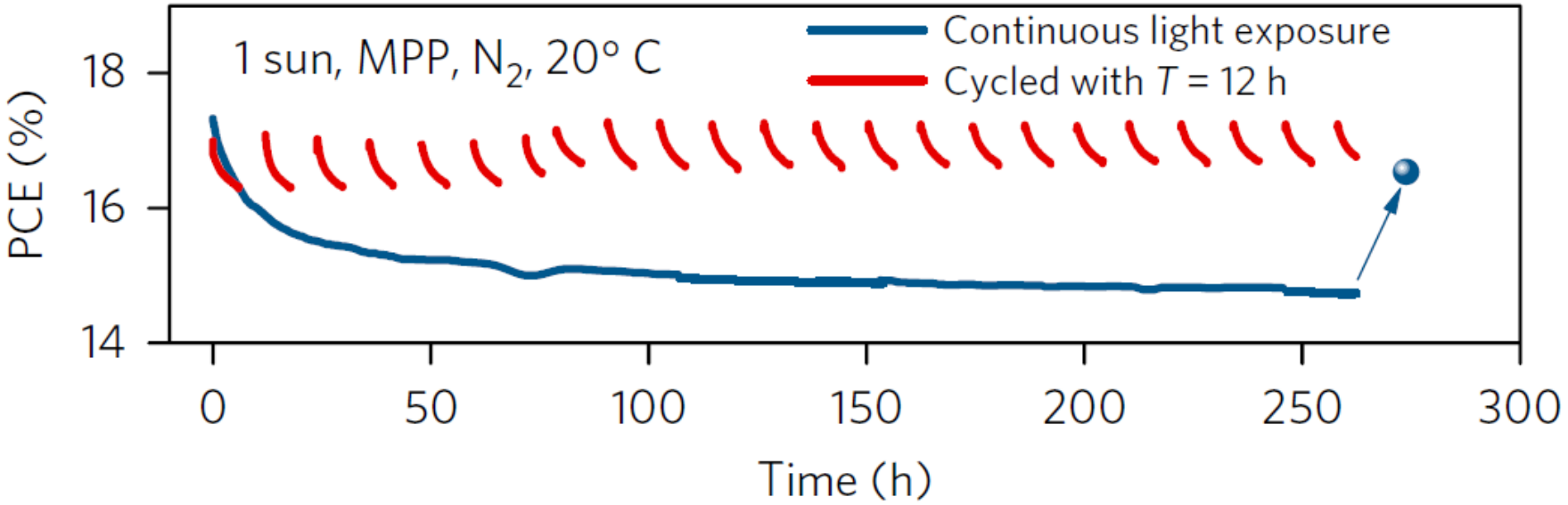
(d)



Tress, J. Phys. Chem Lett. **8**, 3106 (2017)

Transient Effects

Long Term Degradation and Recovery

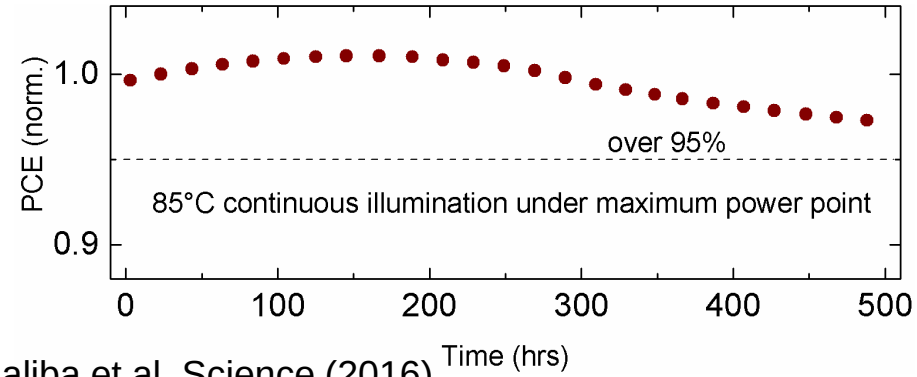


Combination of reversible and irreversible degradation mechanisms.

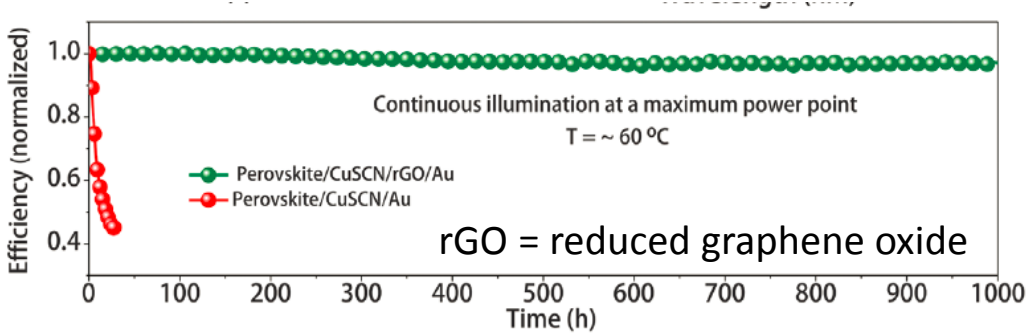
Domanski et al., Nat Energy. **3**, 61 (2018)

Degradation

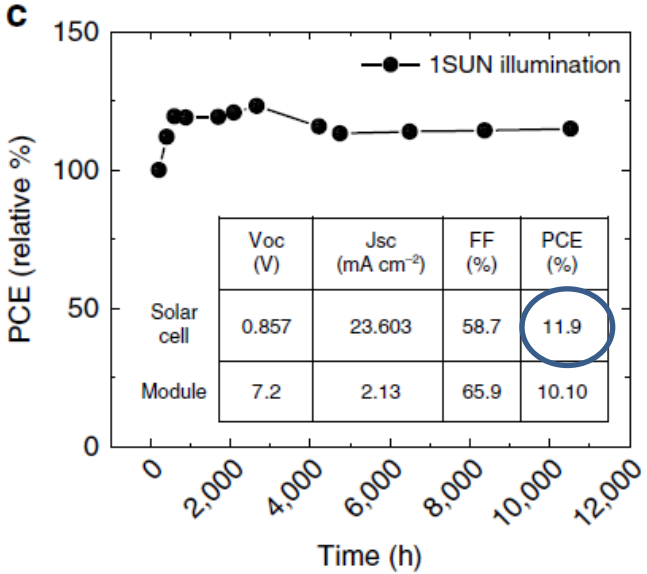
Depends on working point, temperature and contact



Saliba et al. Science (2016)



Arora et al. Science (2017)



Grancini et al. Nat. Comms. (2017)

Summary

Metal-Halide Perovskites

Potential

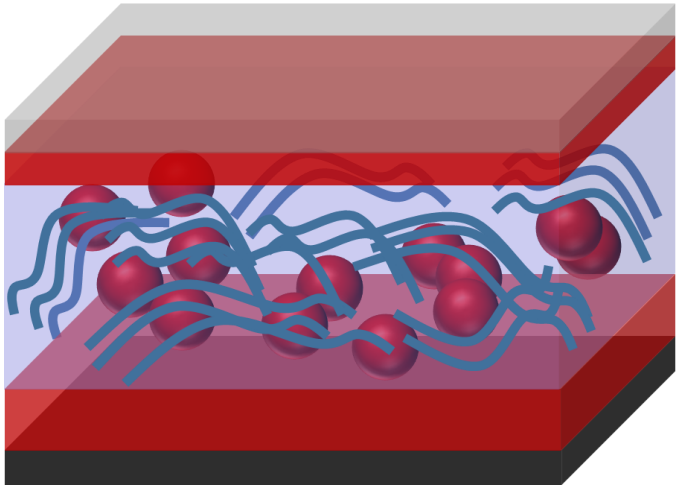
- Efficiencies and long charge carrier lifetimes
- High Band Gaps → Potential for Tandems
- Solution processing (potential for cheap manufacturing)

Challenges

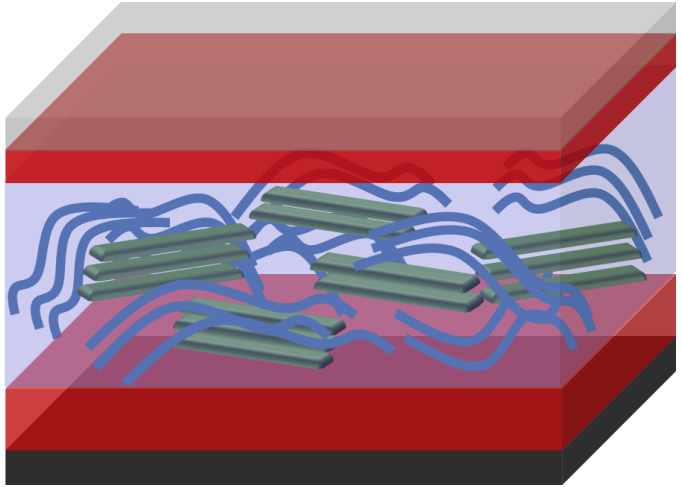
- Many shallow defects → transient effects
- Interaction of contacts with degradation and surface recombination
- Toxicity (heavy atoms → long charge carrier lifetimes?)

Recent trends in solution processable PV

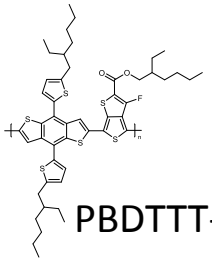
Non-Fullerene Acceptor Materials in Organic PV



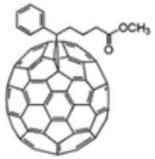
Polymer:Fullerene



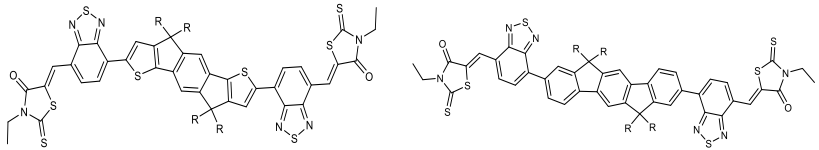
Polymer:NFA



PBDTTT-EFT

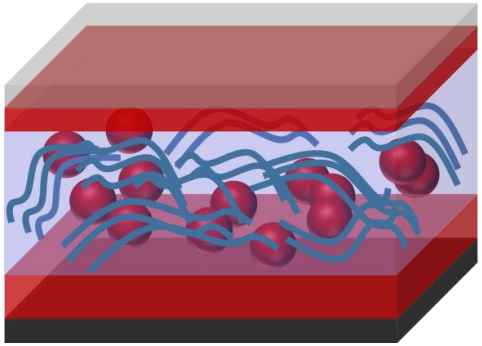


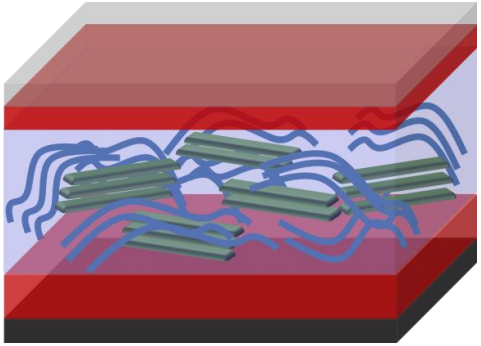
PCBM



Novel acceptor materials (IDTBR, IDFBR)

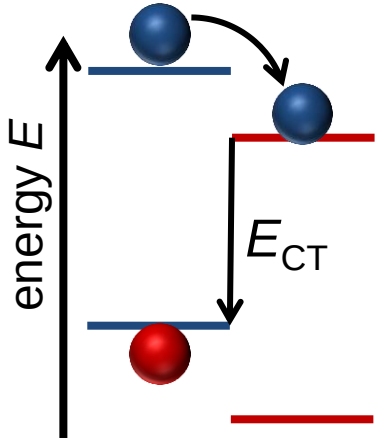
Non-Fullerene Acceptor Materials in Organic PV

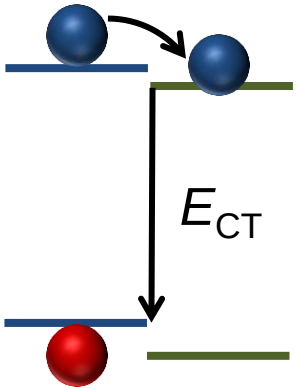


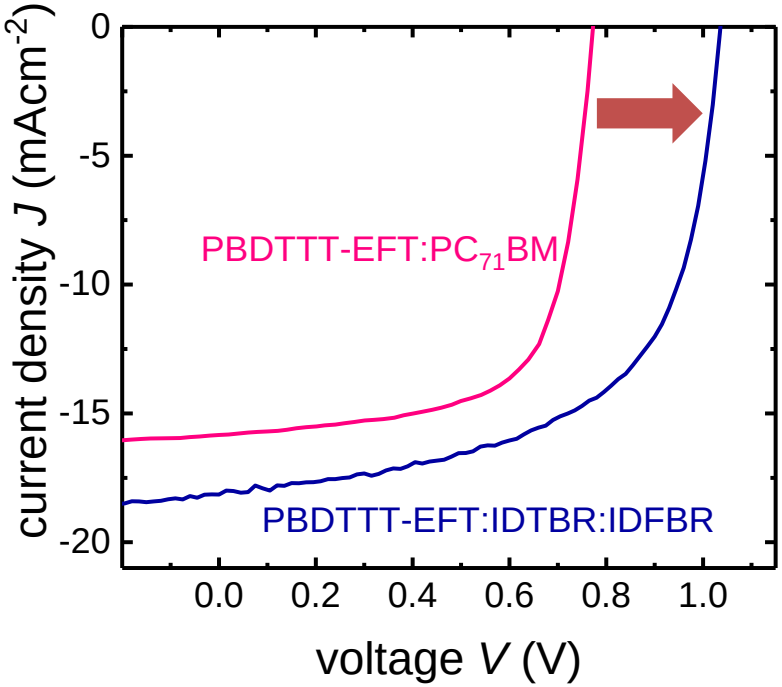


Polymer:Fullerene

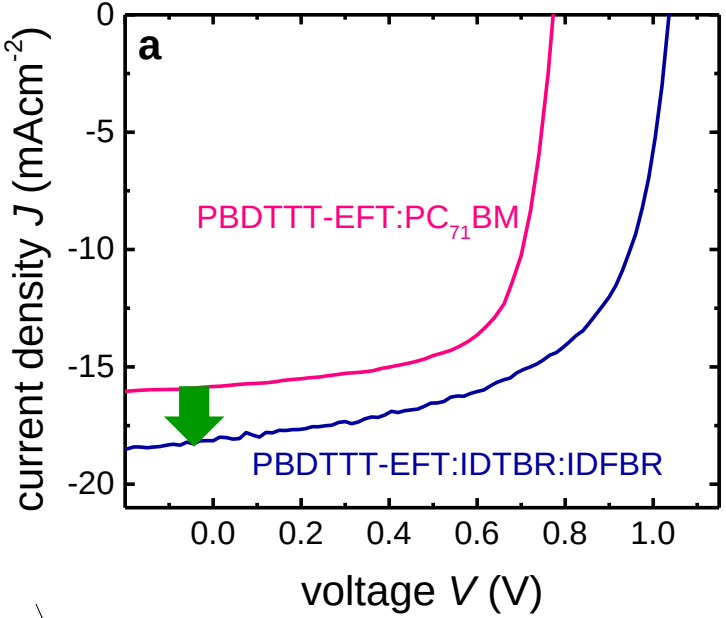
Polymer:NFA

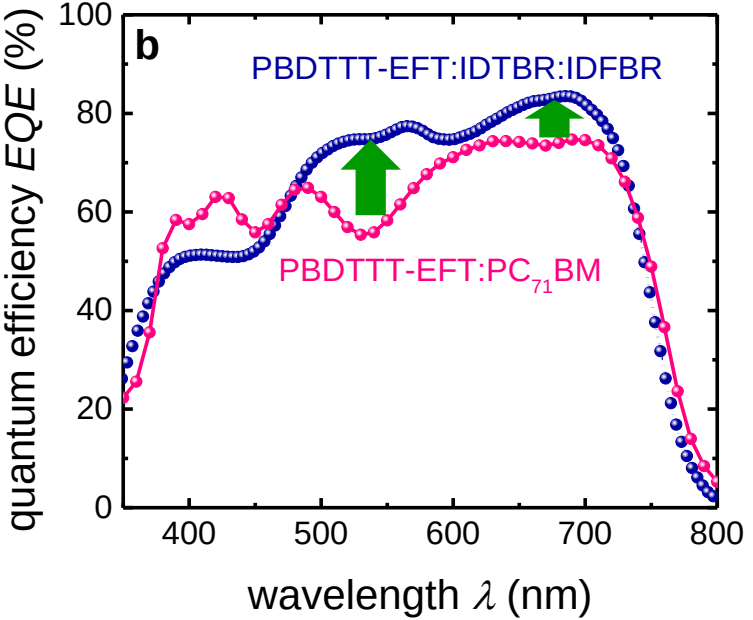


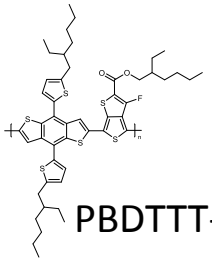




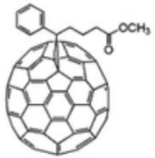
Non-Fullerene Acceptor Materials in Organic PV



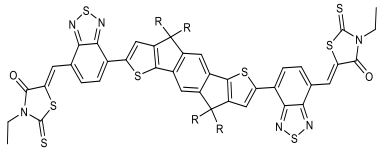


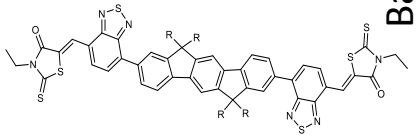


PBDTTT-EFT



PCBM

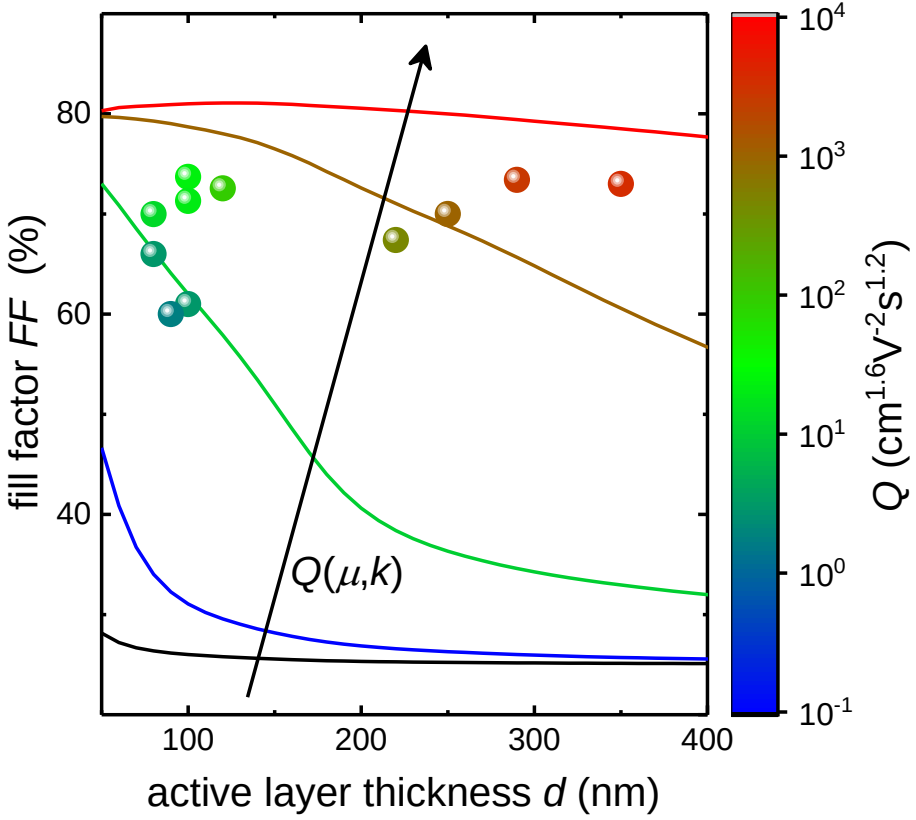


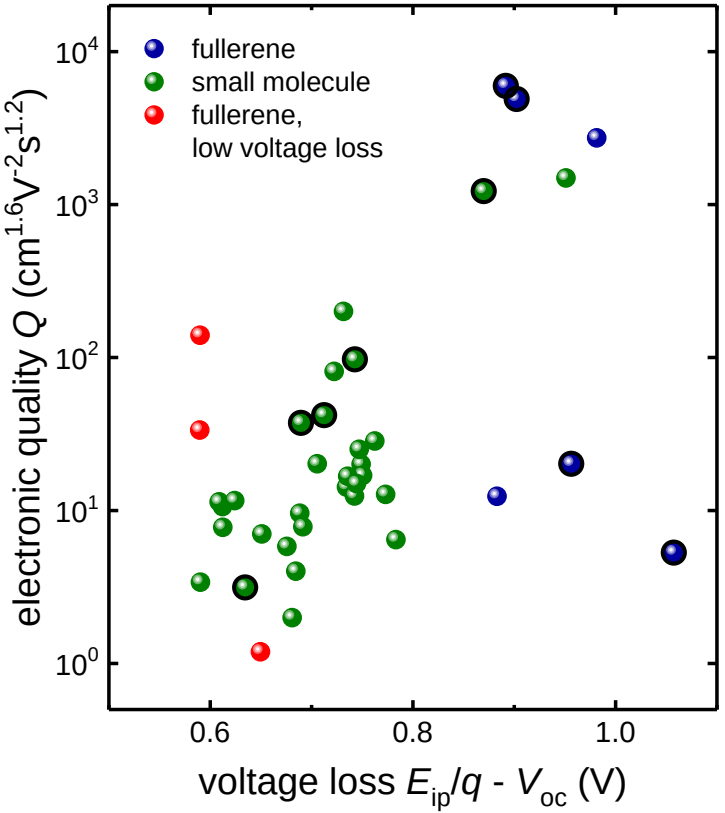


Novel acceptor materials (IDTBR, IDFBR)

Baran et al. Nat. Mater. **16**, 363 (2017)
Baran et al. Energy & Environ. Science **9**, 3783 (2016)

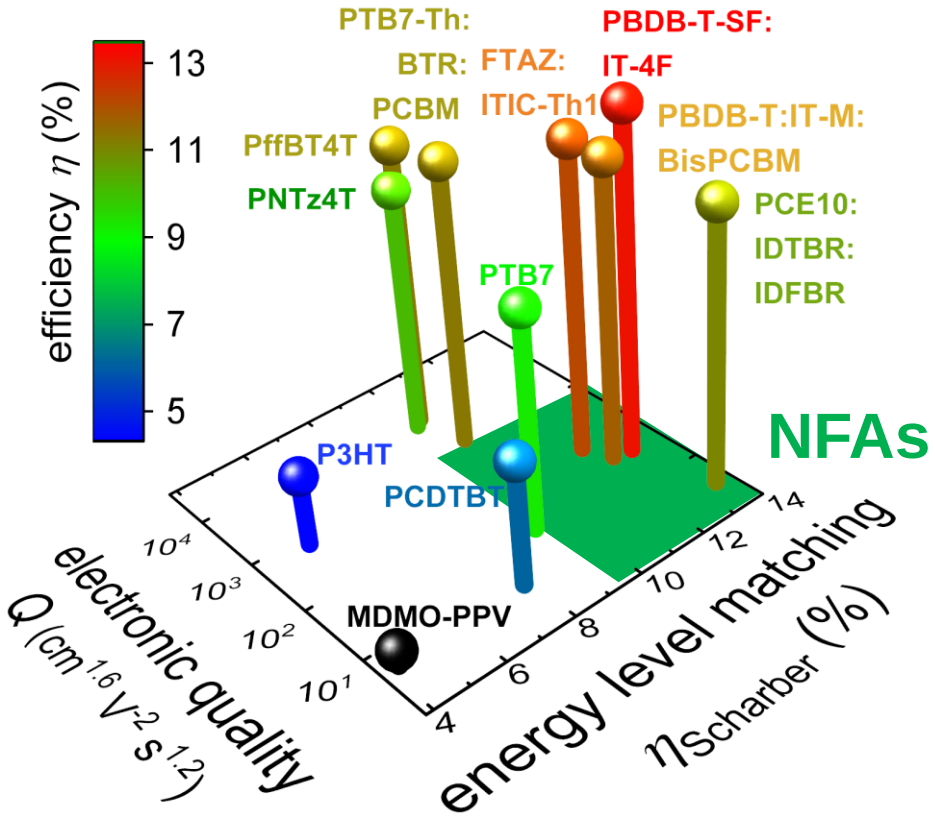
Charge Transport

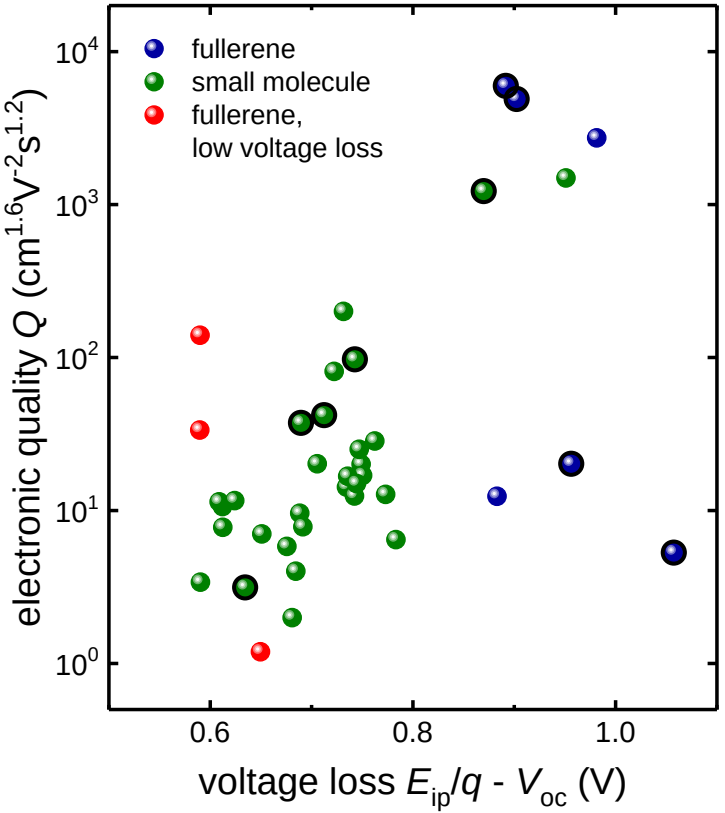




Kirchartz et al. J. Phys. Chem. C (2018)

Charge Transport





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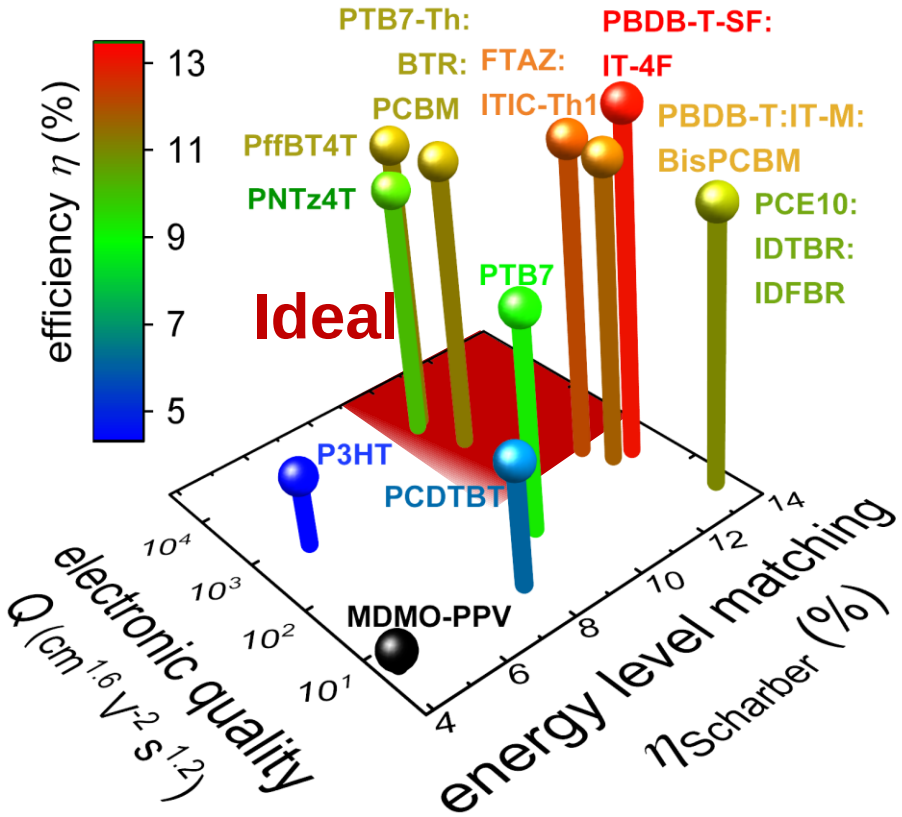

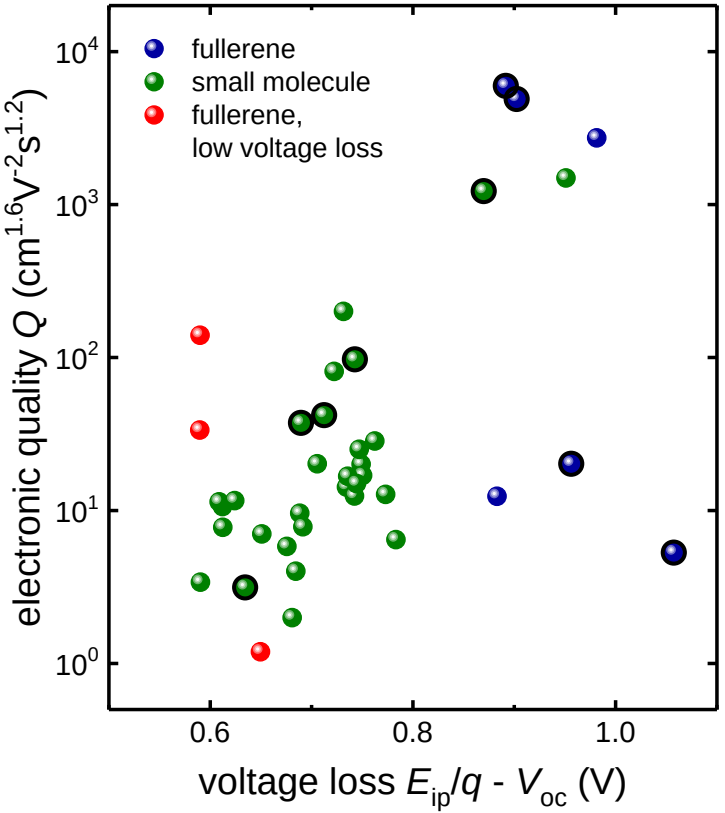

Kirchartz et al. J. Phys. Chem. C (2018)

Summary

Organic Solar Cells

Potential

- Efficiencies are improving again thanks to NFAs
- Variable band gaps (tandems are also possible)
- Solution processing (potential for cheap manufacturing)
- Many degrees of freedom in organic synthesis

Challenges

- Rapid testing (how to identify promising materials?)
- Charge Transport is main hindrance at the moment
- Stability

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

JÜLICH Forschungszentrum

Thank you for your attention

Thanks to
Derya Baran, Florian Staub, Pascal Kaienburg, David Egger and Uwe Rau

and Helmholtz for funding!