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Australian Centre for Advanced Photovoltaics

"Emergence of Perovskite Solar Cells"

Martin A. Green

University of New South Wales (UNSW)

Sydney, Australia

ARENA

Australian Government

Australian Renewable Energy Agency

Photovoltaics - Electricity from Sunlight

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Science and Nature agree: Big solar news of 2013!

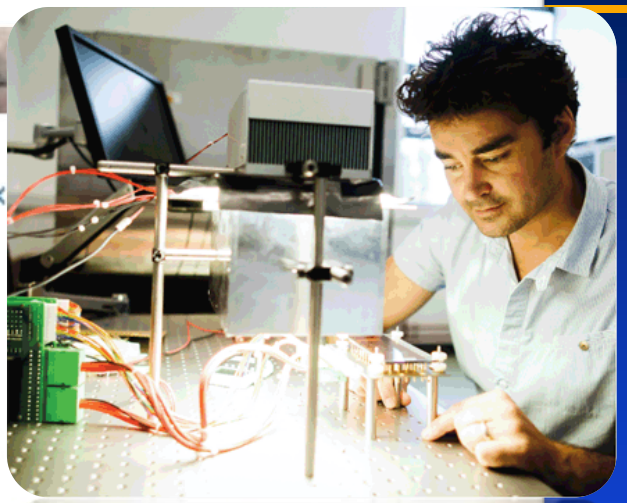
BREAKTHROUGH OF THE YEAR

Science 20 December 2013:
Vol. 342 no. 6165 pp. 1438–1439
DOI: 10.1126/science.342.6165.1438-b

NEWS

Newcomer Juices Up the Race to Harness Sunlight

Up-and-coming solar cell materials called perovskites made such rapid progress this year that the editors of *Science* picked them as a runner-up for Breakthrough of the Year.



365 days: *Nature*'s 10

Ten people who mattered this year.

18 December 2013

HENRY SNAITH: Sun worshipper

An energetic physicist pushes a promising solar-cell material into the spotlight.

By Mark Peplow

Douglas Fry/Piranha Photography

"I always wanted to be an inventor," says Henry Snaith happily. The 35-year-old physicist at the University of Oxford, UK, has fulfilled that childhood ambition in spectacular style.

y from Sunlight

EU PVSEC 2013

28th European PV Solar Energy Conference and Exhibition

Nature photonics review (July 2014)

nature photonics

REVIEW ARTICLE

PUBLISHED ONLINE: XX JULY 2014 | DOI: 10.1038/NPHOTON.2014.134

The emergence of perovskite solar cells

Martin A. Green[1], Anita Ho-Baillie[1] and Henry J. Snaith[2]

The past two years have seen the unprecedentedly rapid emergence of a new class of solar cell based on mixed organic–inorganic halide perovskites. Although the first efficient solid-state perovskite cells were reported only in mid-2012, extremely rapid progress was made during 2013 with energy conversion efficiencies reaching a confirmed 16.2% at the end of the year. This increased to a confirmed efficiency of 17.9% in early 2014, with unconfirmed values as high as 19.3% claimed. Moreover, a broad range of different fabrication approaches and device concepts is represented among the highest performing devices — this diversity suggests that performance is still far from fully optimized. This Review briefly outlines notable achievements to date, describes the unique attributes of these perovskites leading to their rapid emergence and discusses challenges facing the successful development and commercialization of perovskite solar cells.

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Photovolta

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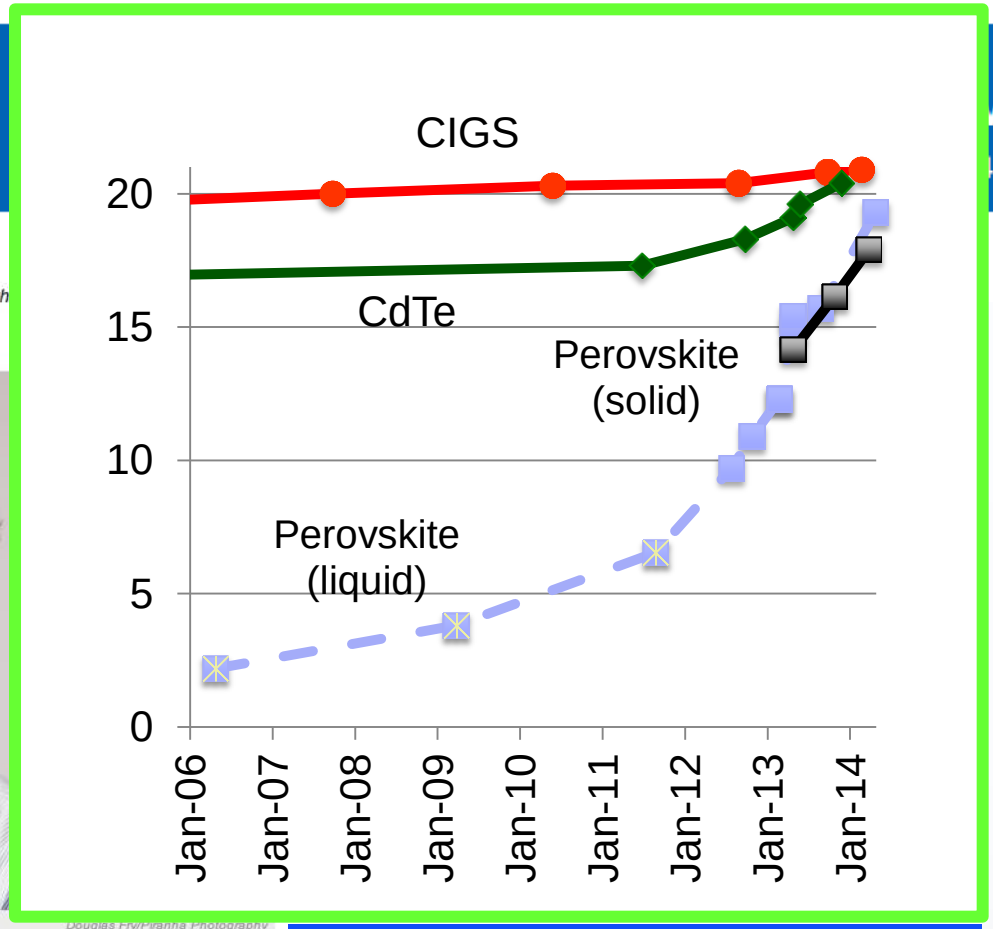

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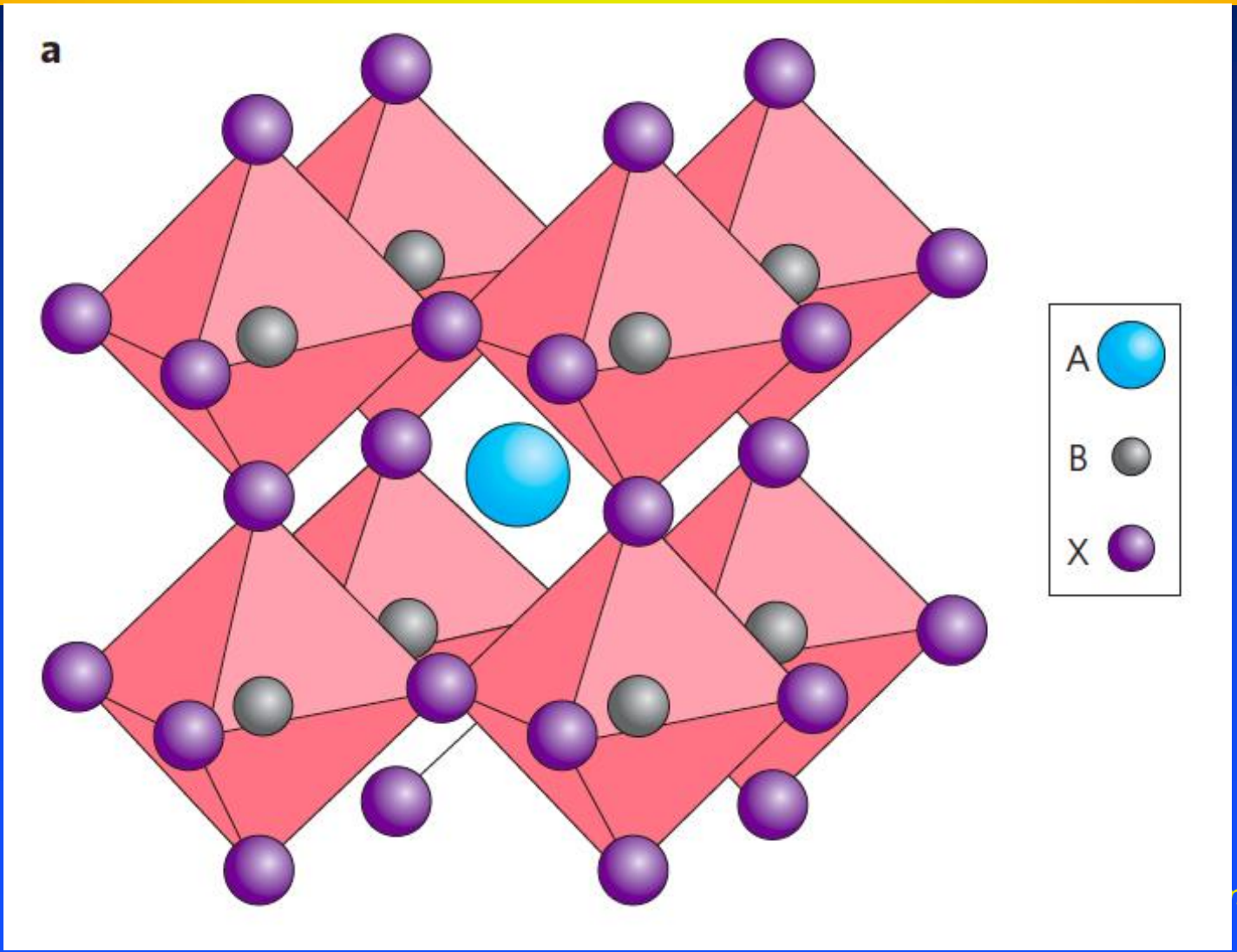
Perovskite

$CH_3NH_3PbI_3$



CH_3NH_3

Pb

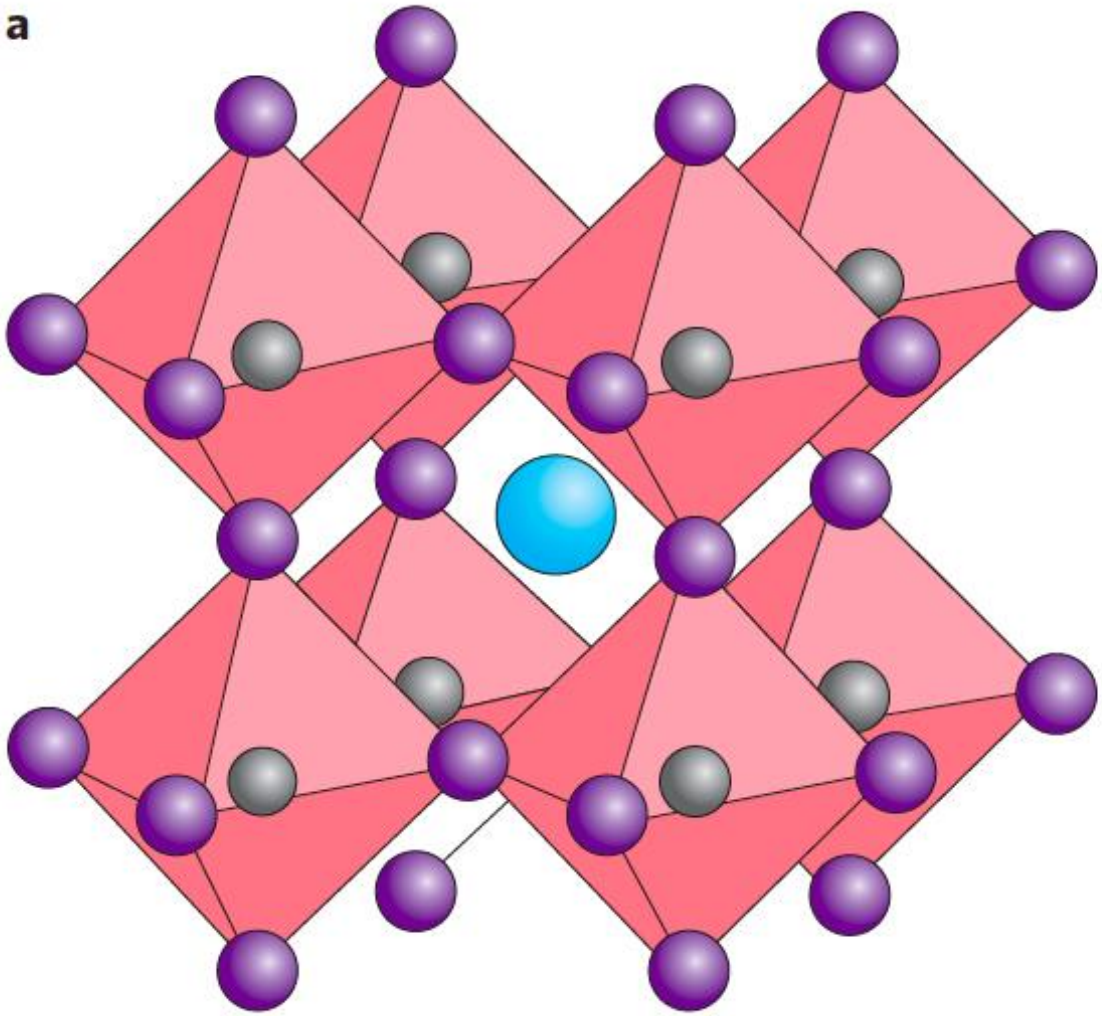
I

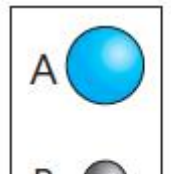
UNSW

n Sunlight

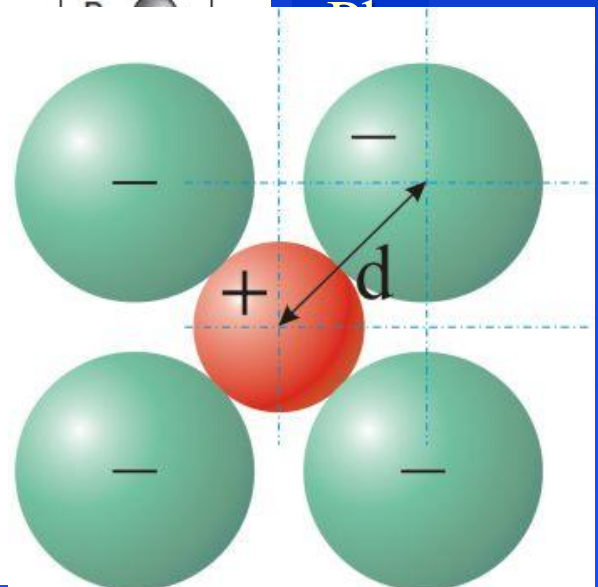
Perovskite

$CH_3NH_3PbI_3$





CH_3NH_3



UNSW

Perovskite

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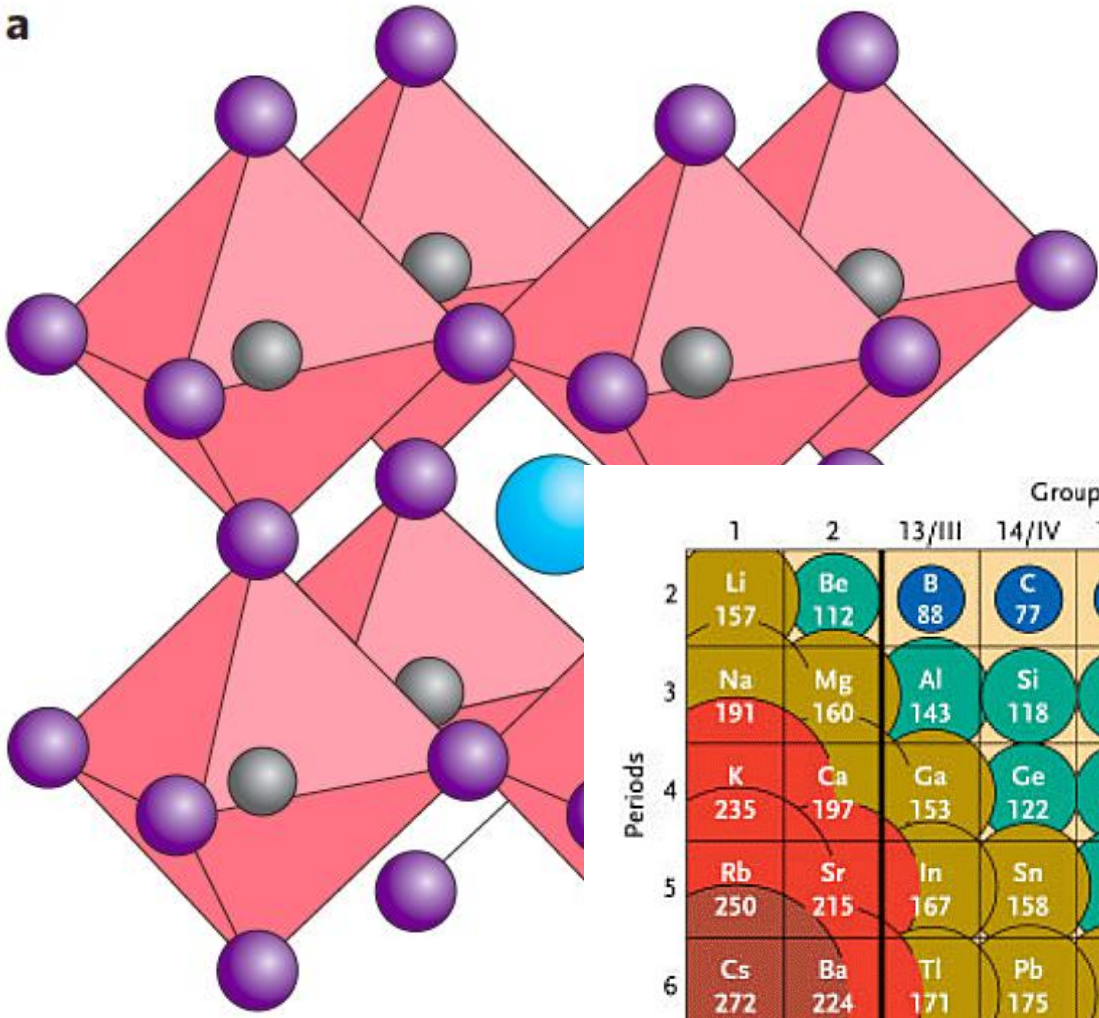
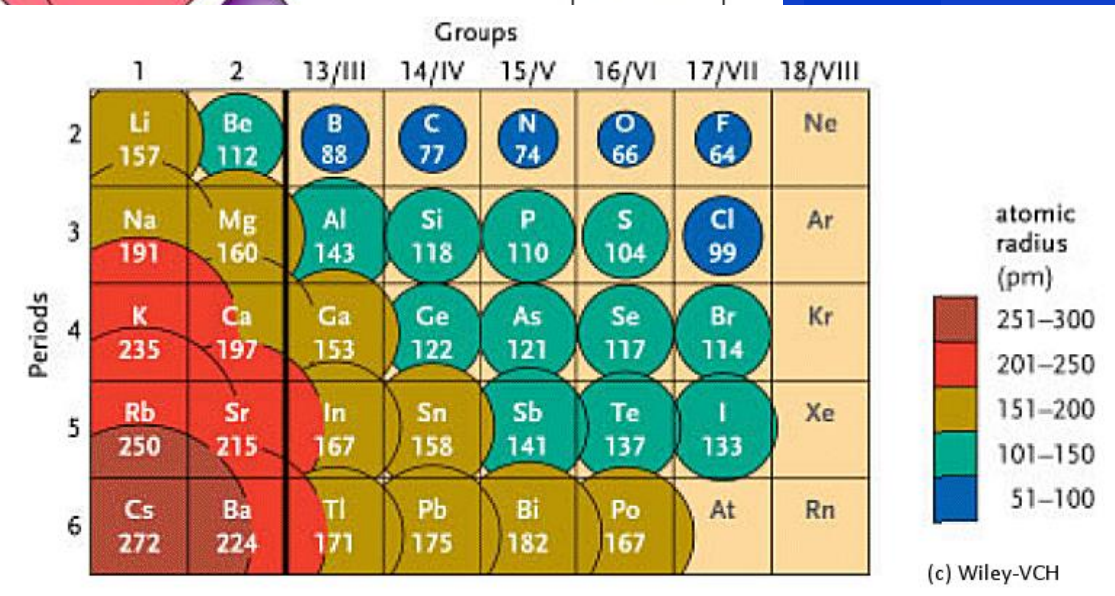
CH_3NH_3





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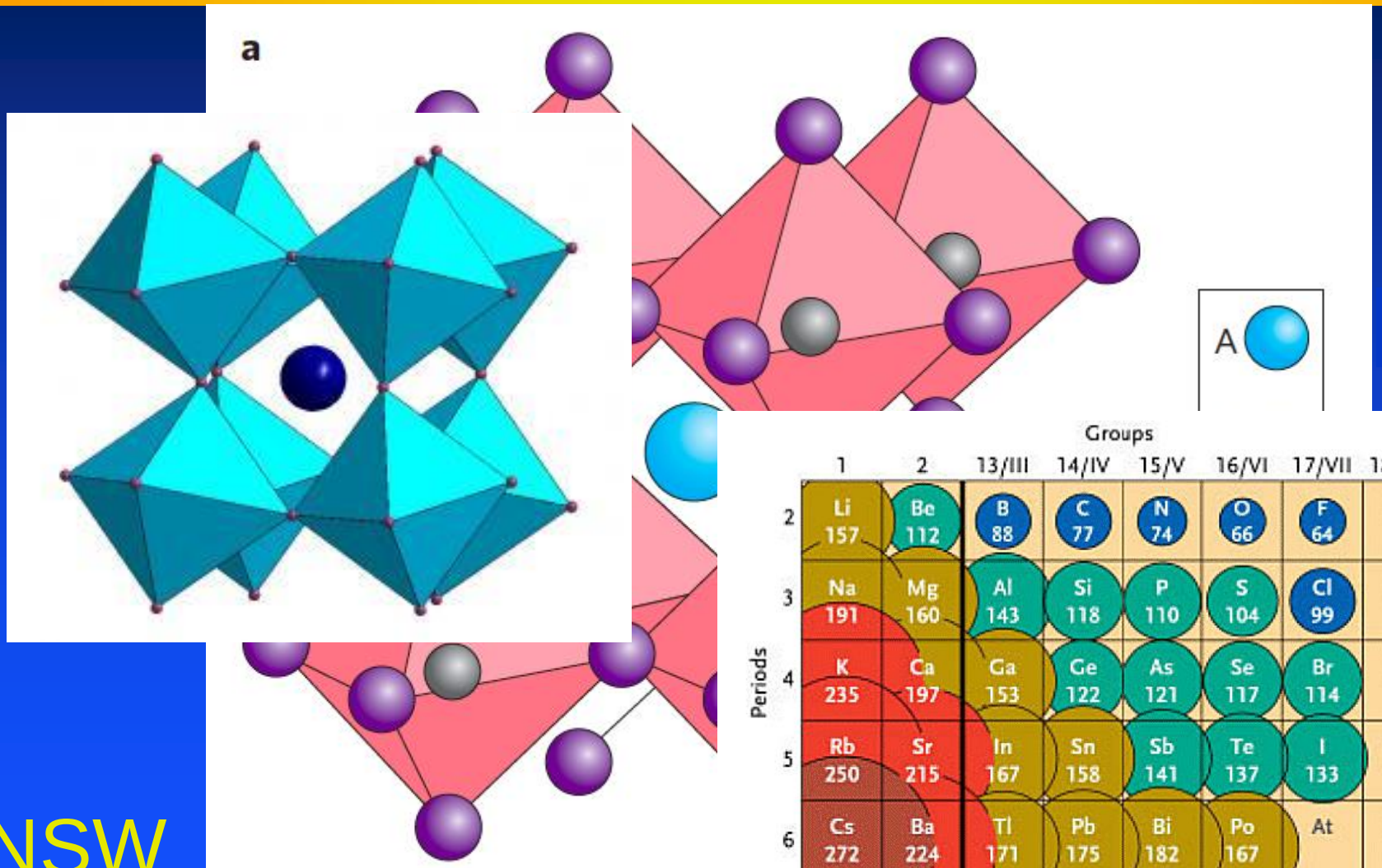
Perovskite



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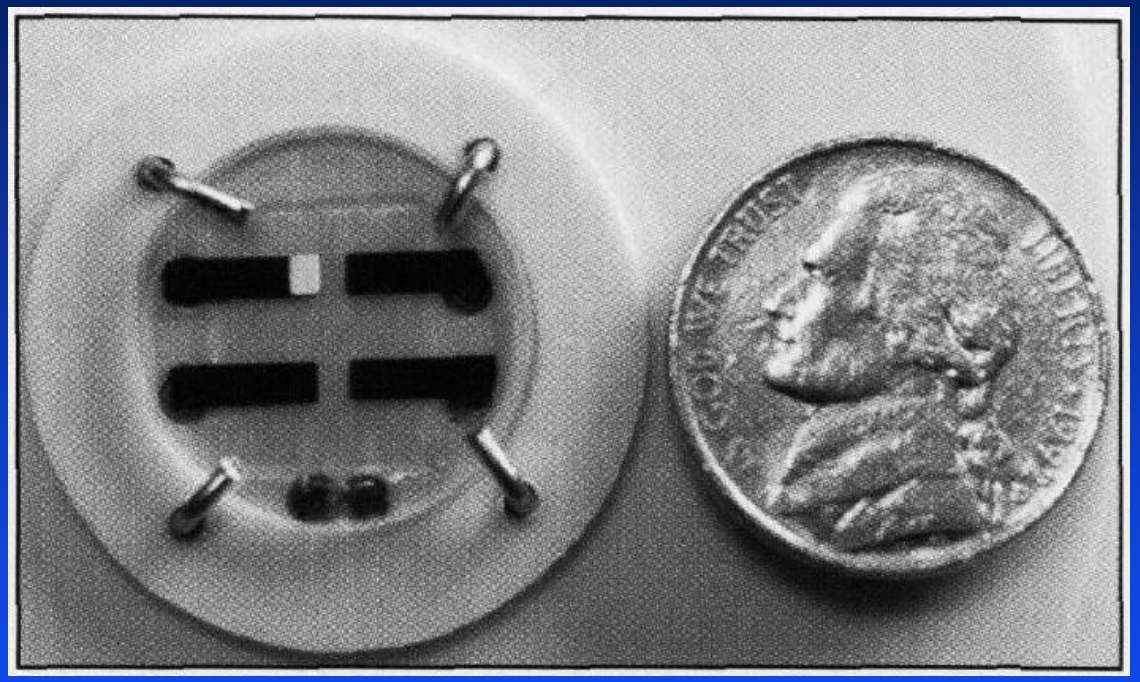
History



David Mitzi then at IBM

From 1995 ~ 2002, investigated use in LEDs and FETs

Pb toxicity issue for PV as well as stability – even worse for Sn compounds

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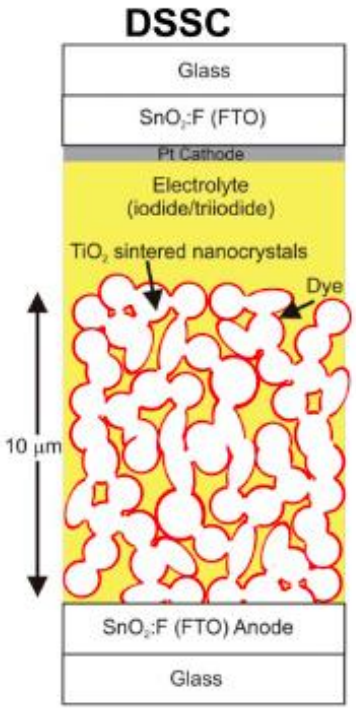
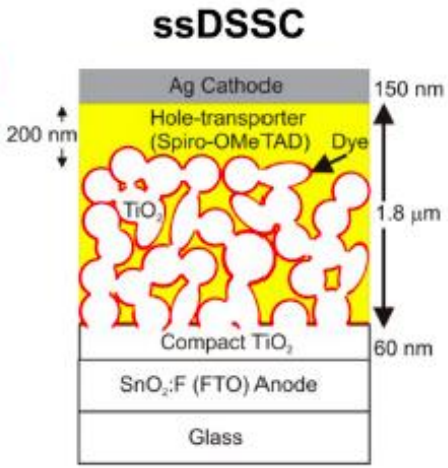
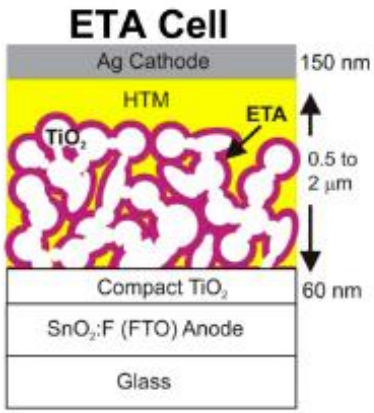
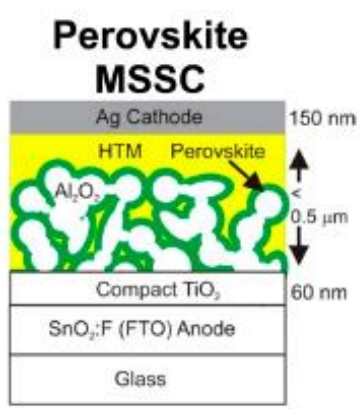
Perovskite Evolution

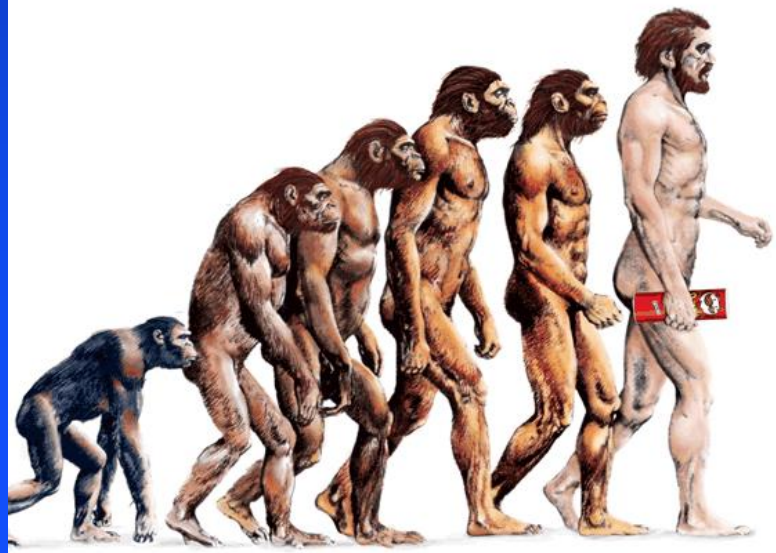
Snaith, H.J. Phys. Chem. Lett. 2013, 4, 3623





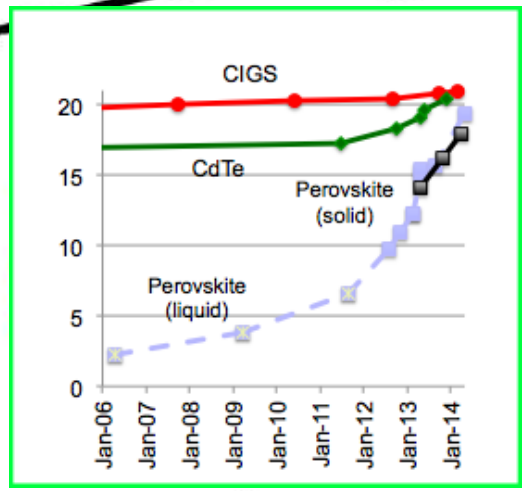






Future direction

"p-i-n" thin-film perovskite



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Perovskite Evolution

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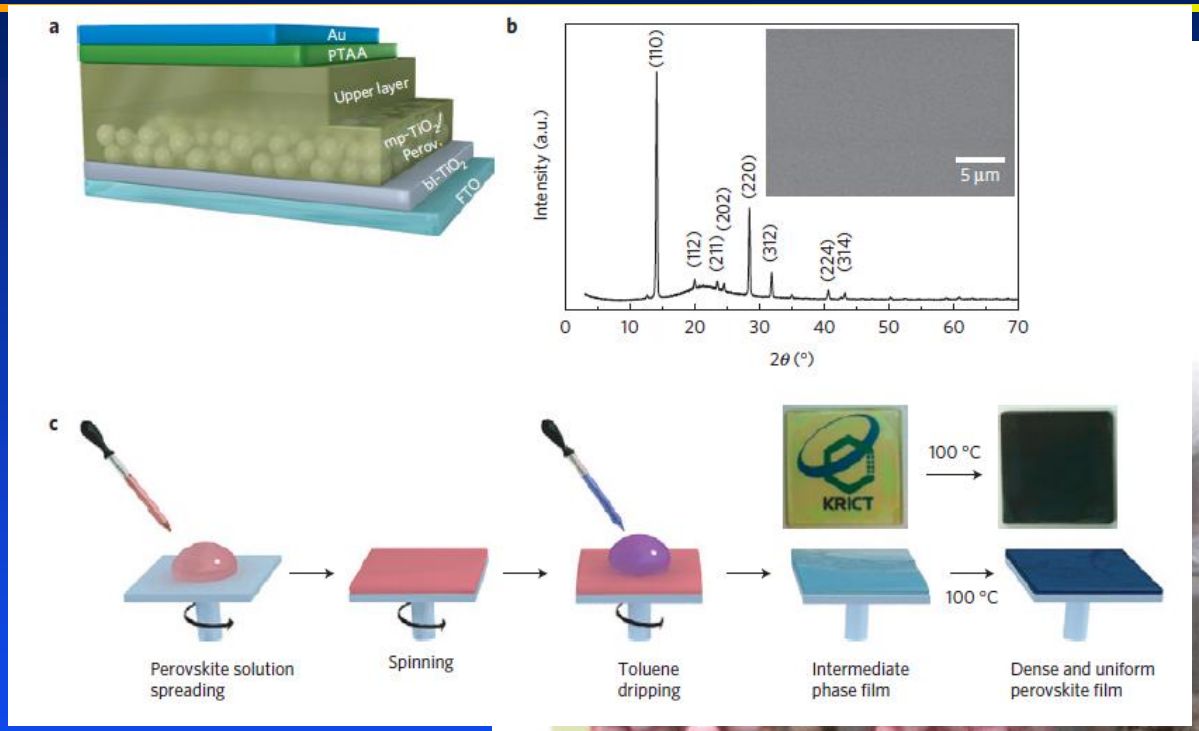
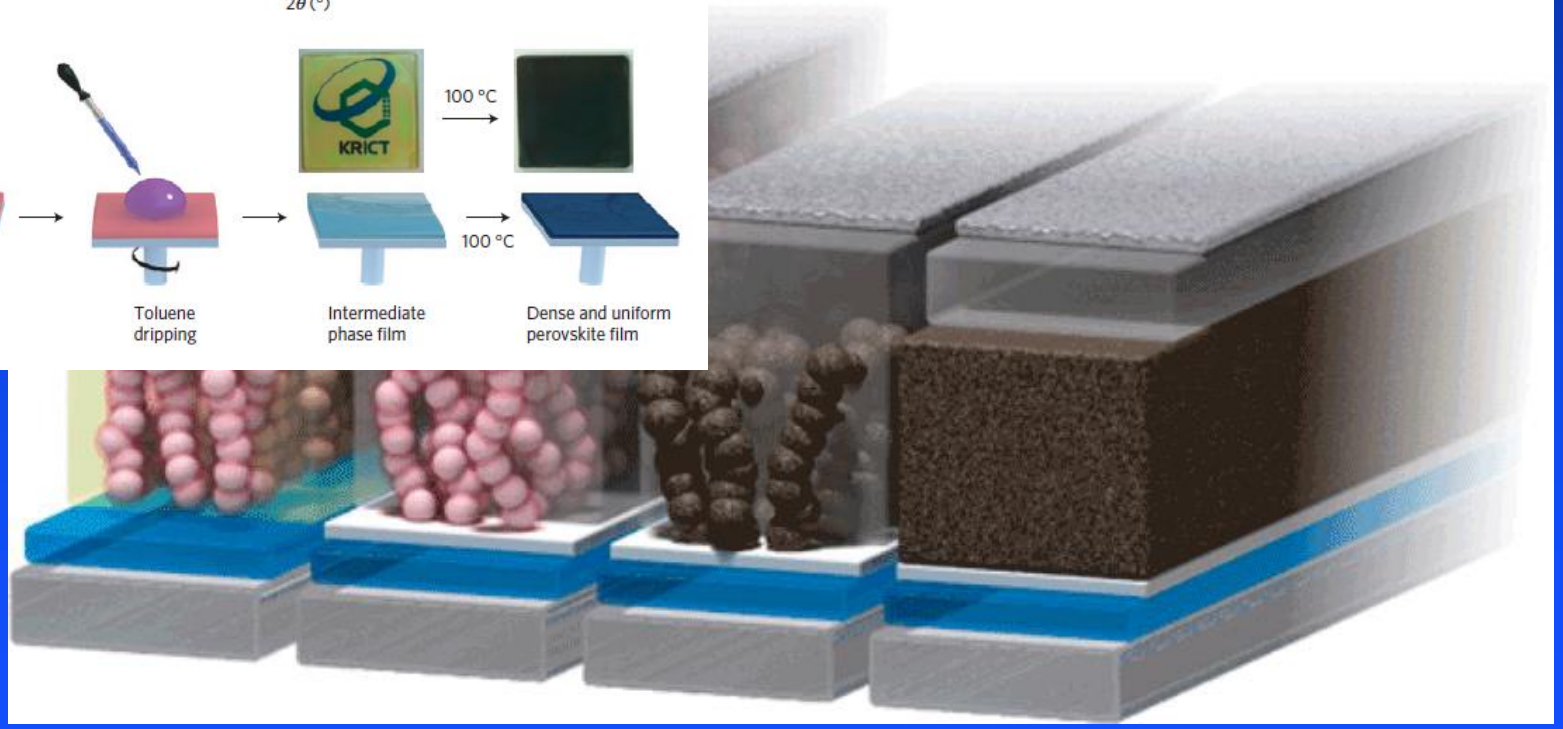
Liquids



Snaith, H.J. Phys. Chem. Lett. 2013, 4, 3623



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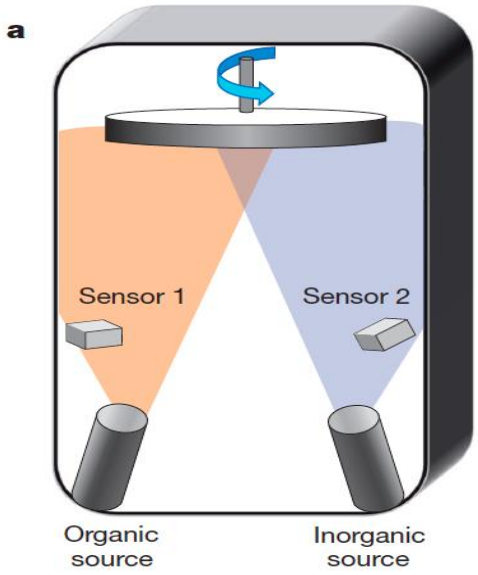
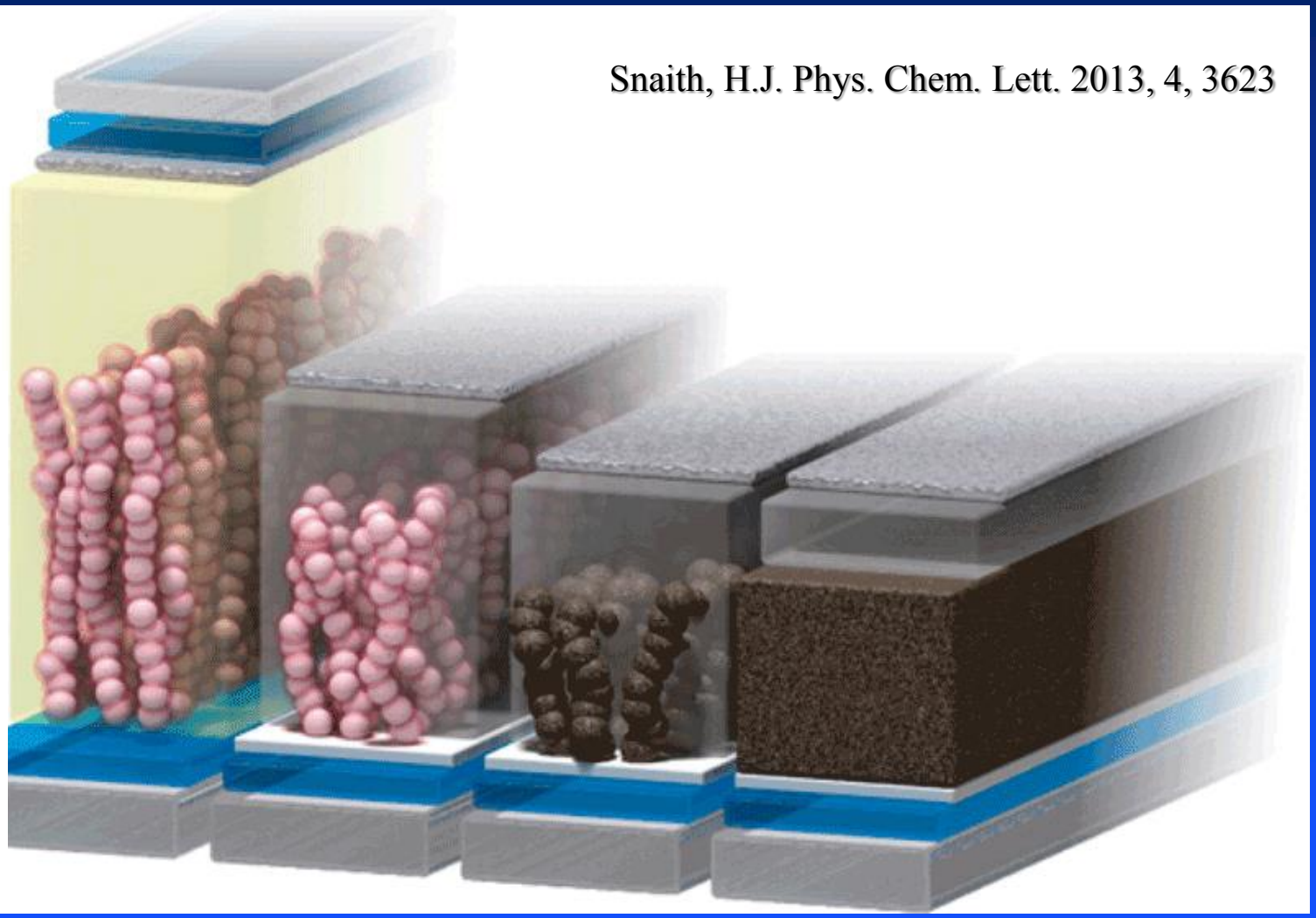
Evaporation





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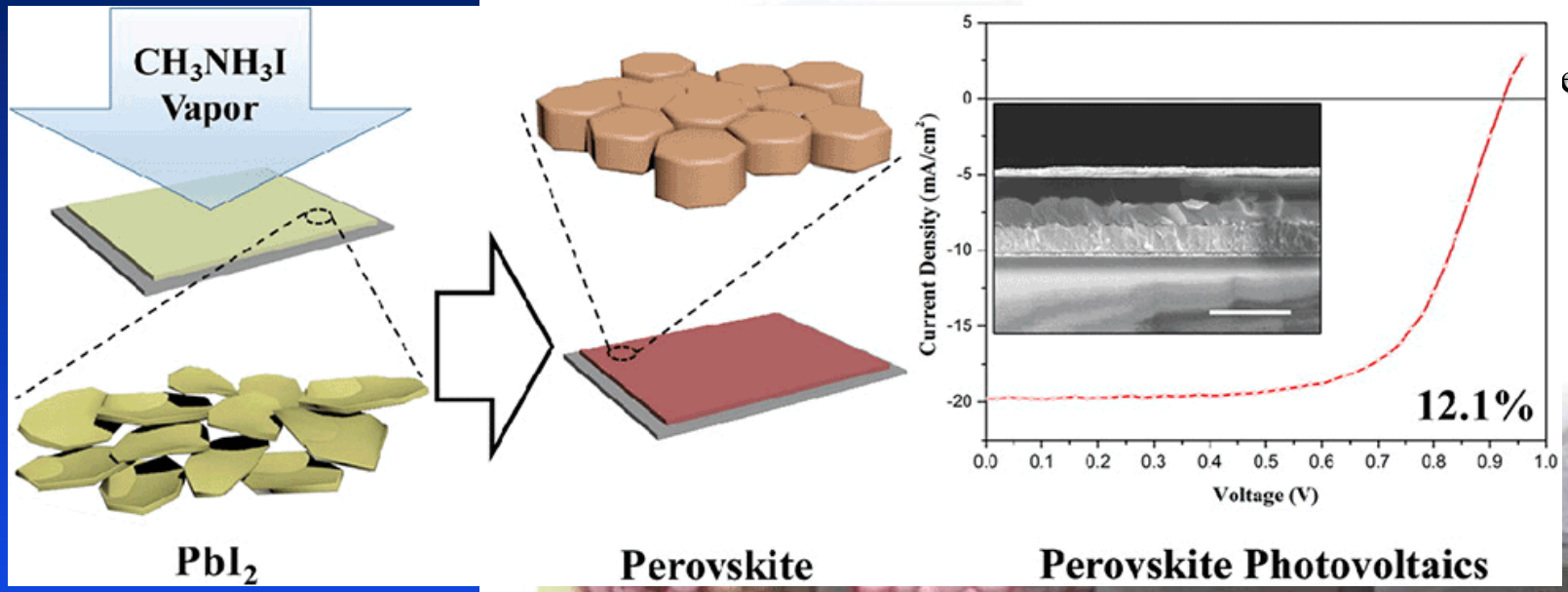
Vapour phase



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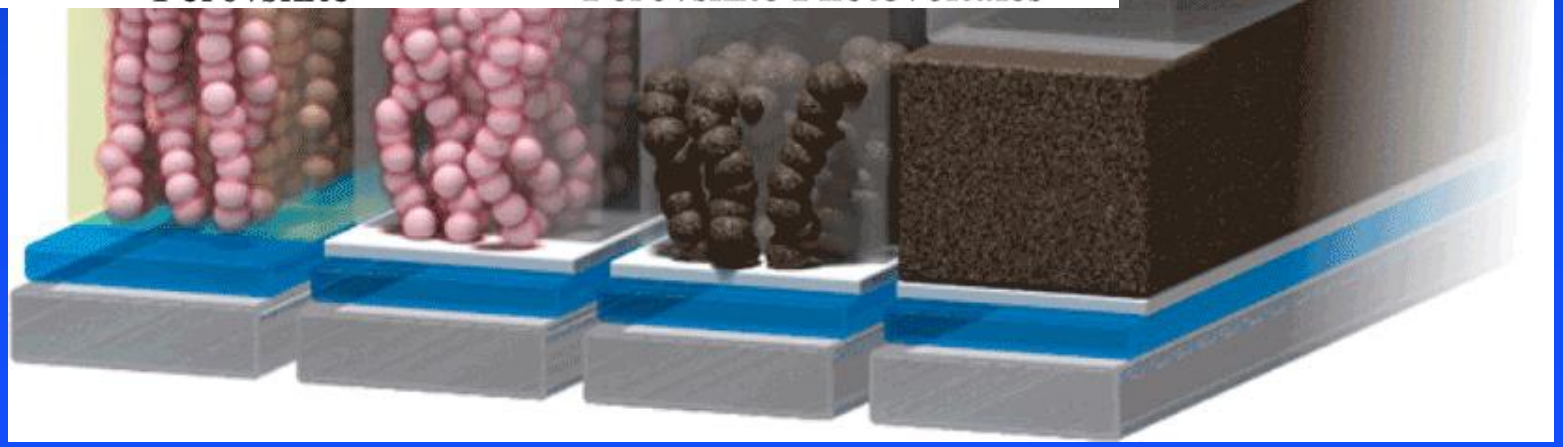
Perovskite Photovoltaics



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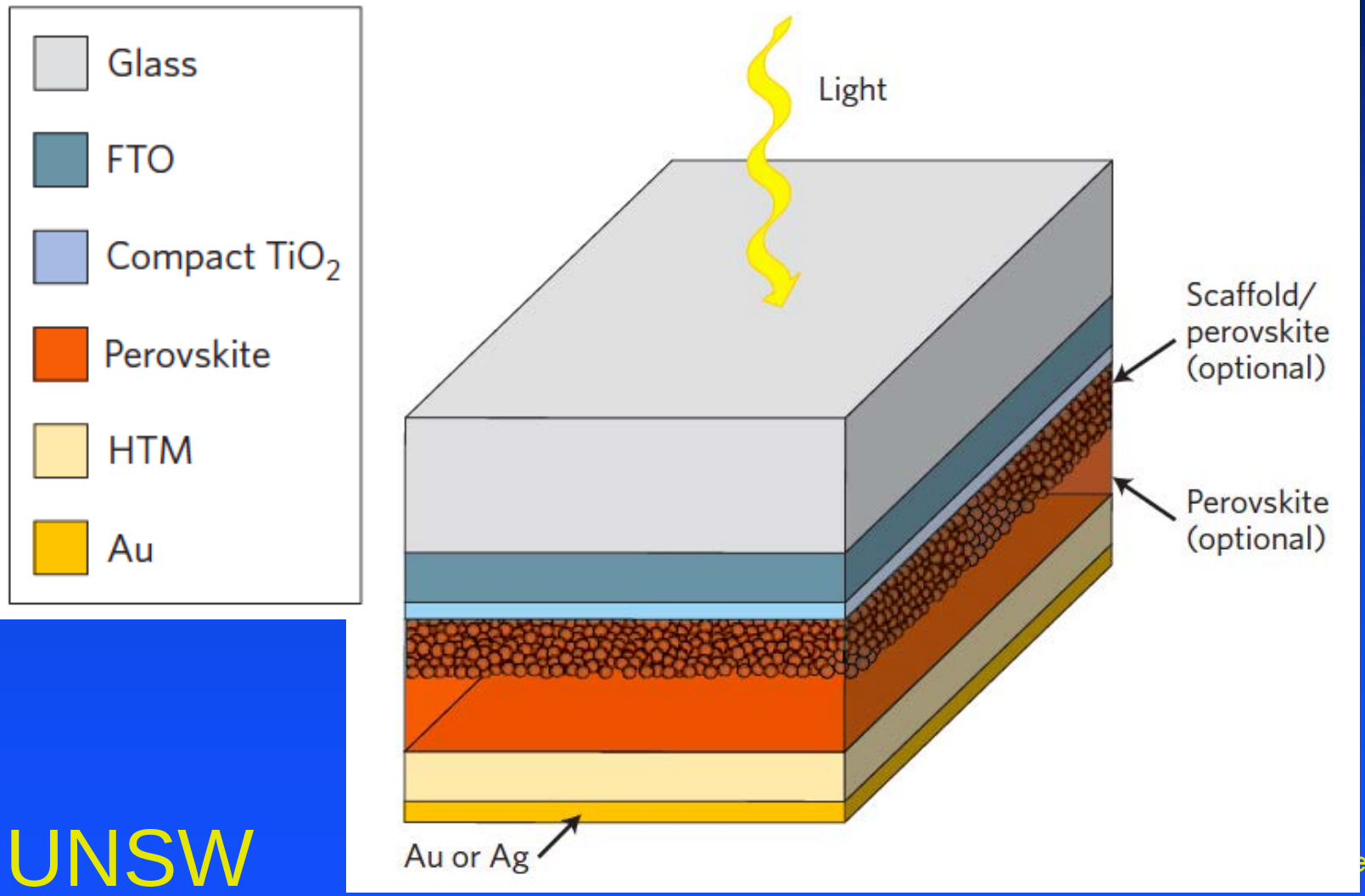
Device structure



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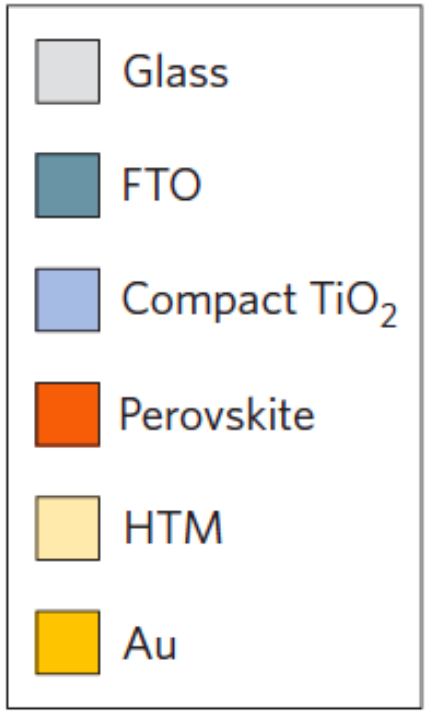
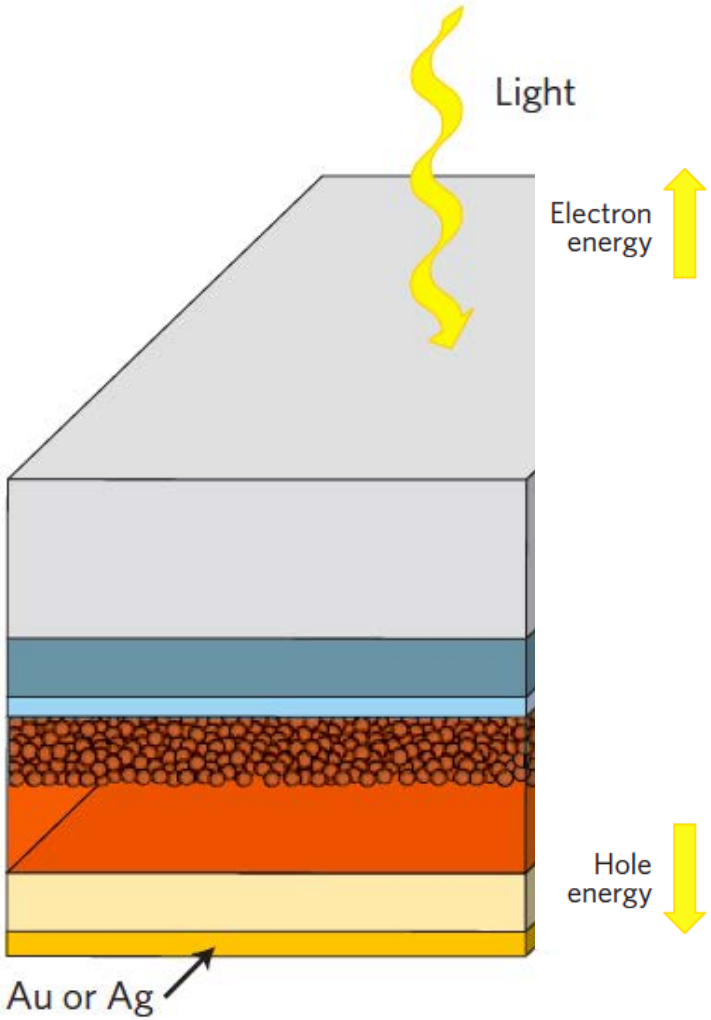
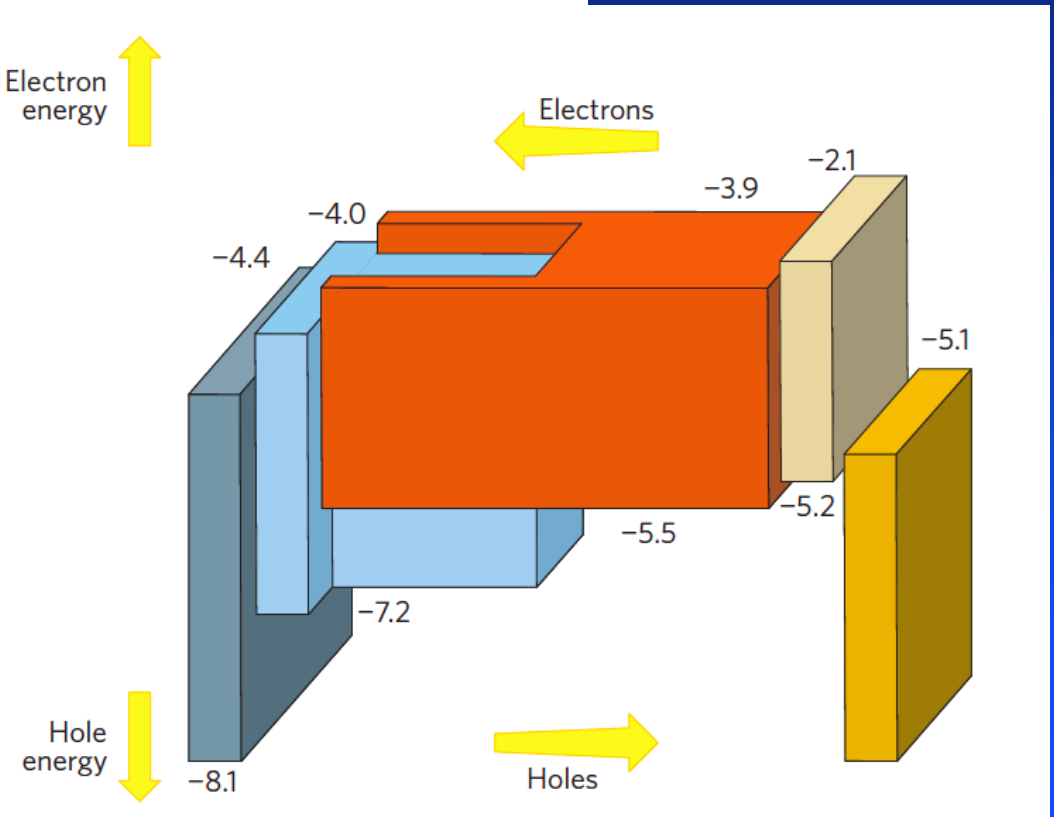
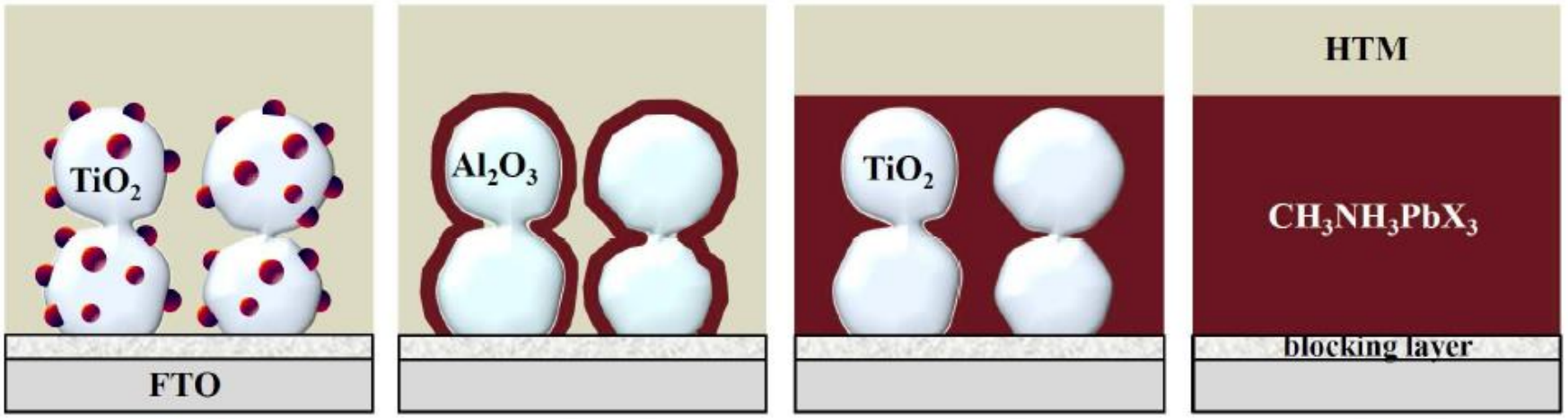






Operating principles



HS Kim, SH Im, and N-G Park J. Phys. Chem. C, DOI: 10.1021/jp409025w

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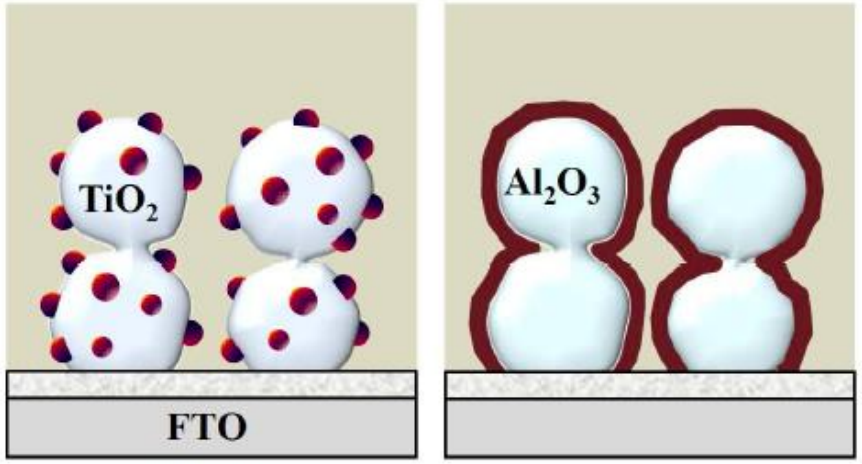

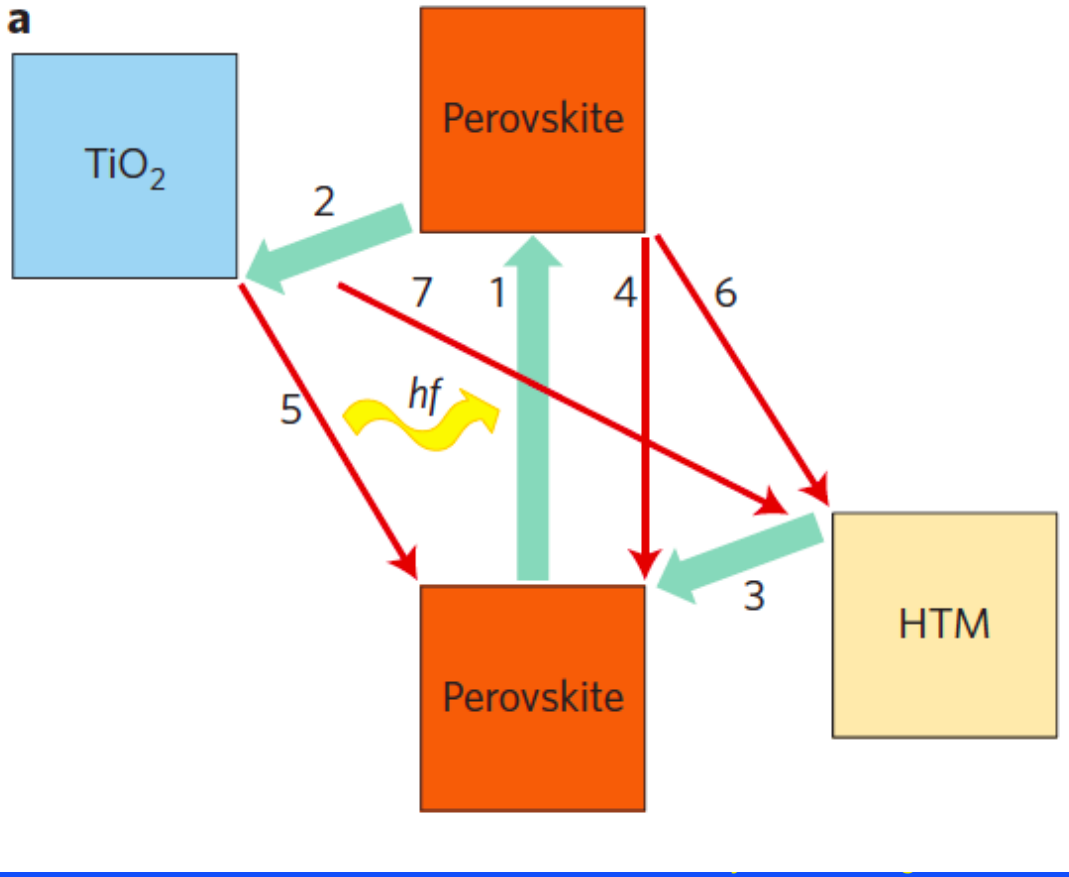

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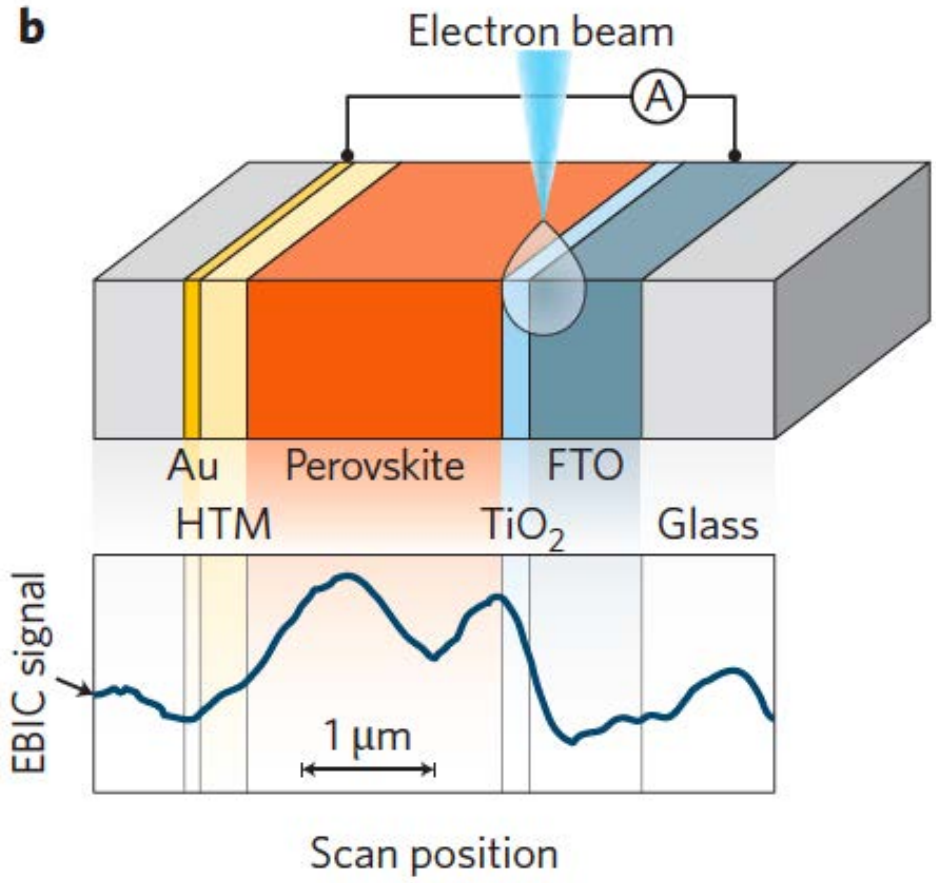

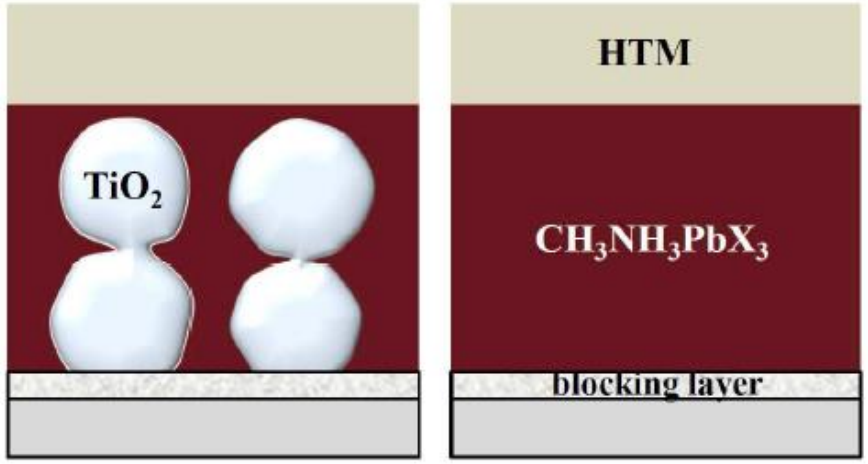

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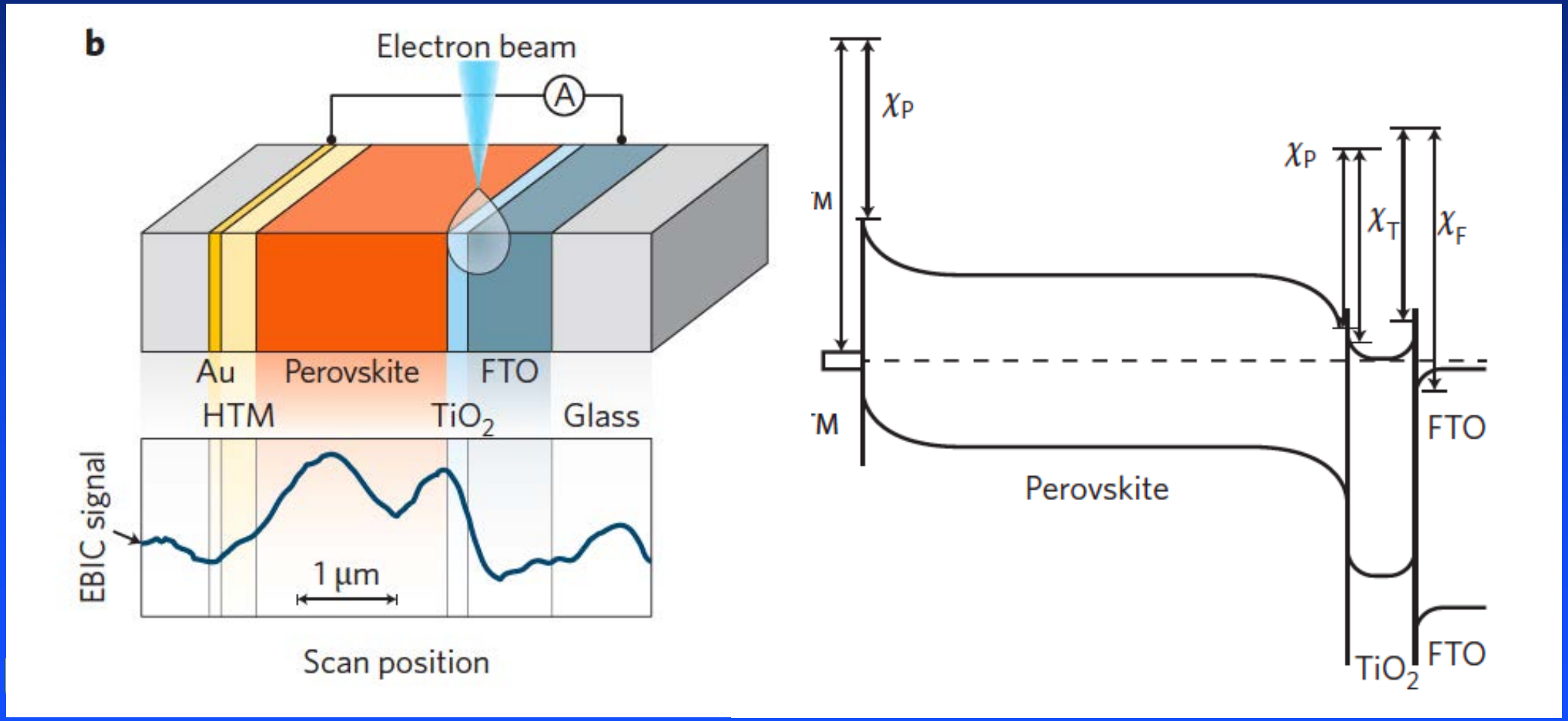
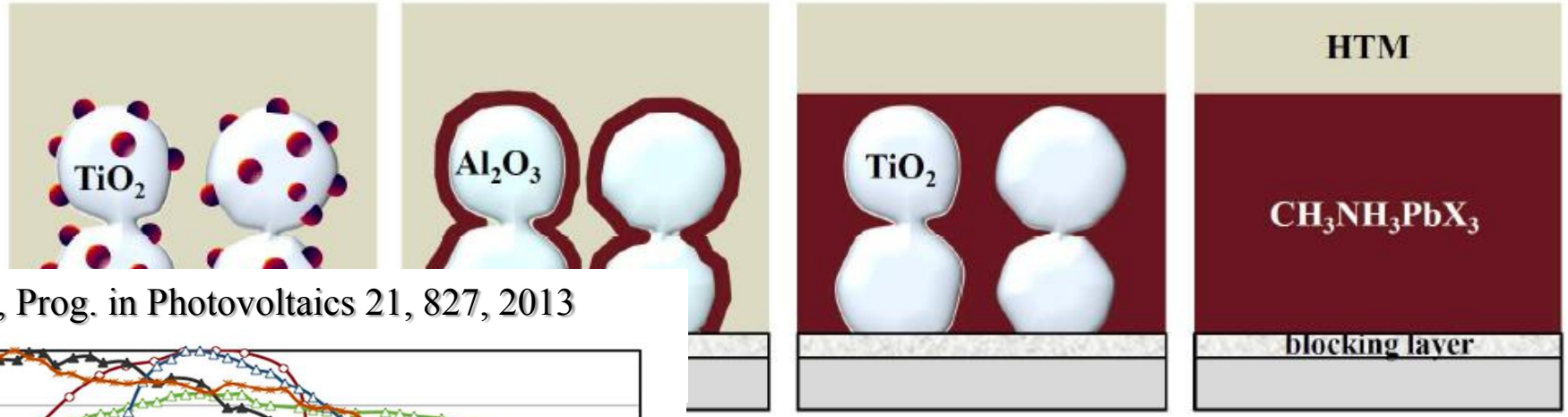
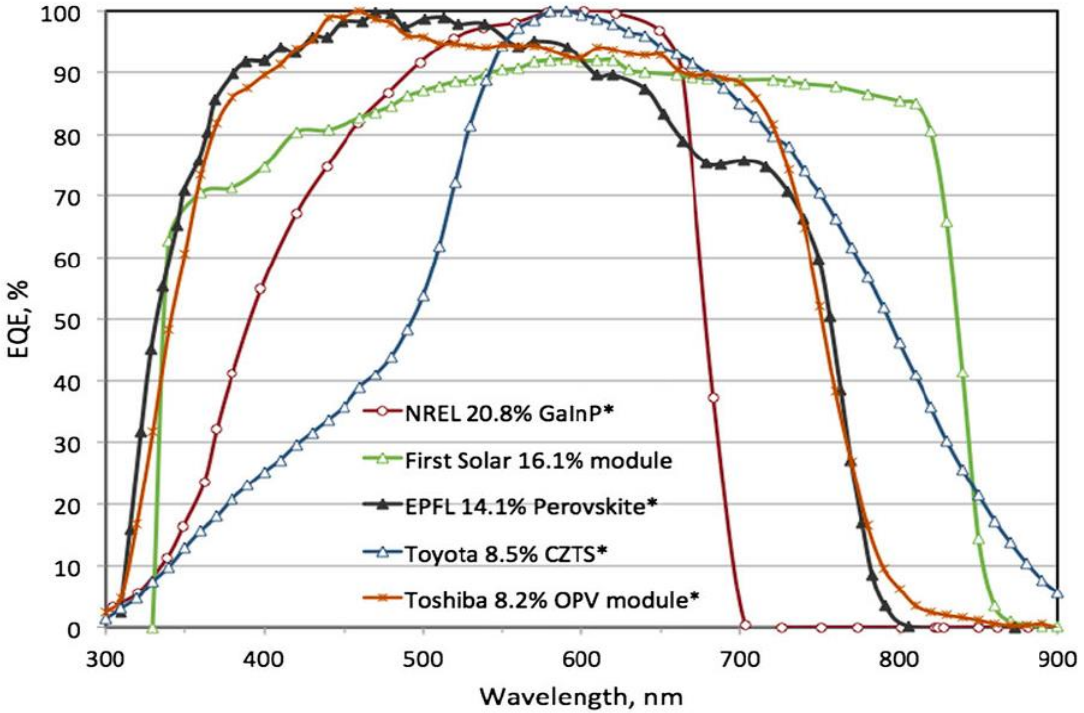


High Voc – low recombination



MA Green at al., Prog. in Photovoltaics 21, 827, 2013



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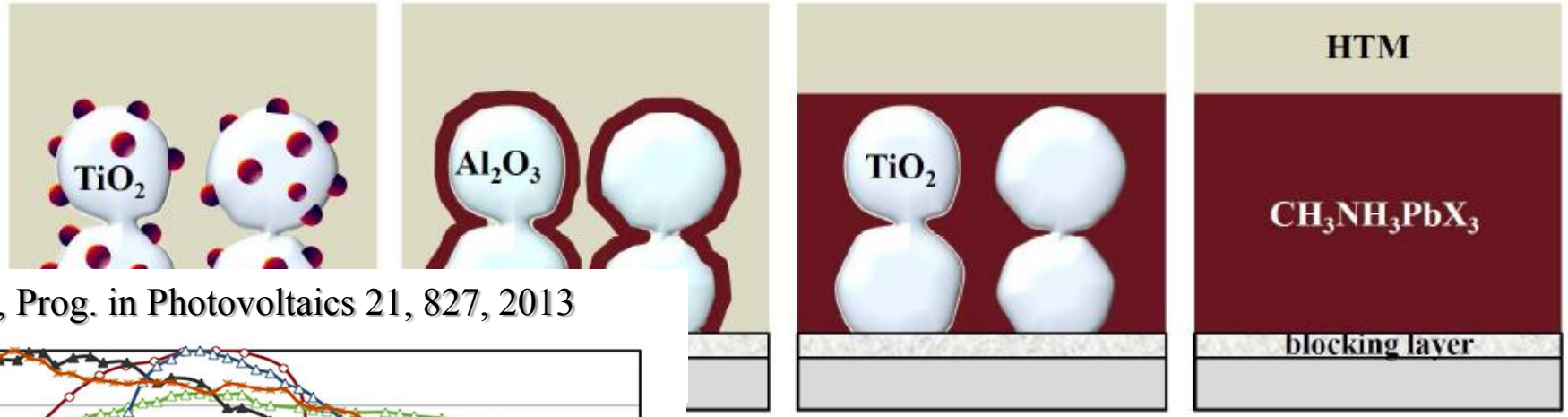

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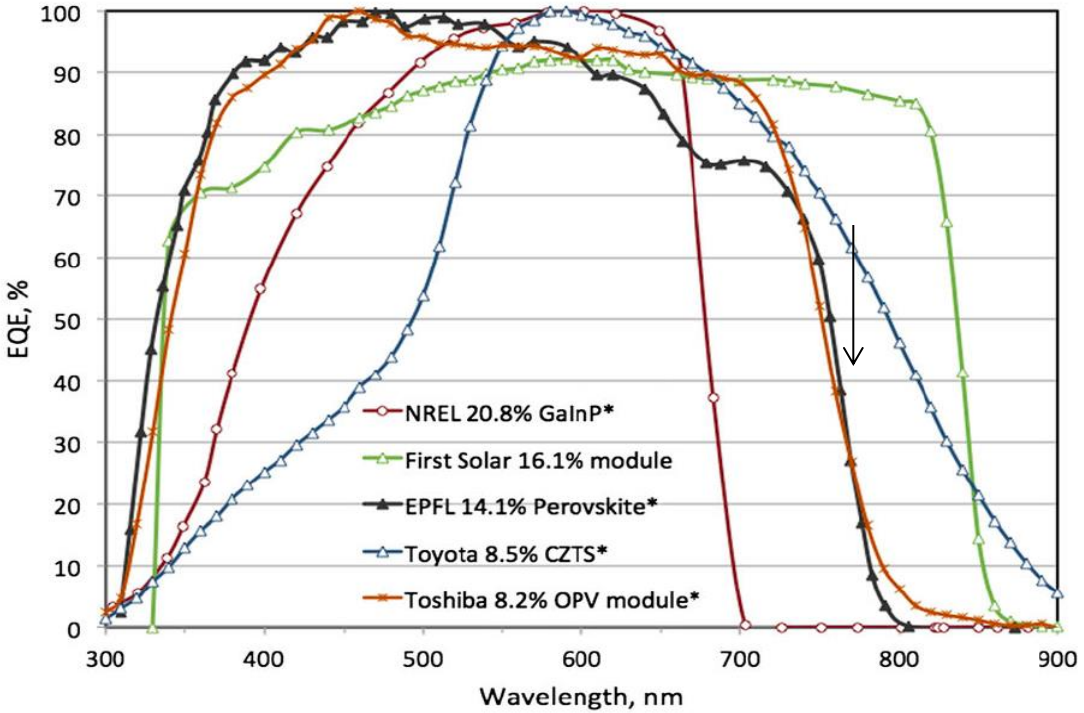

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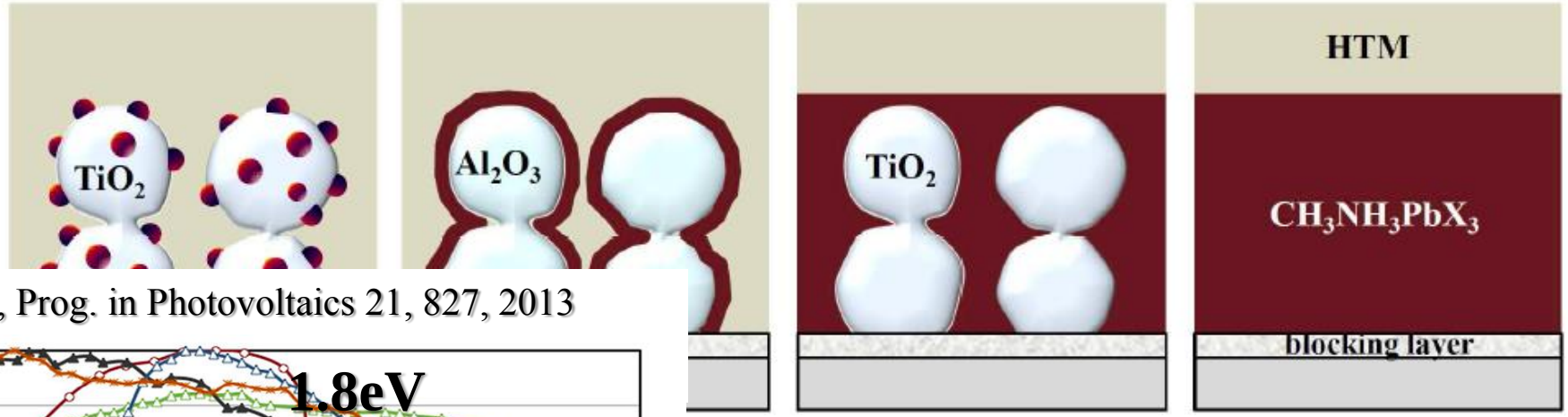

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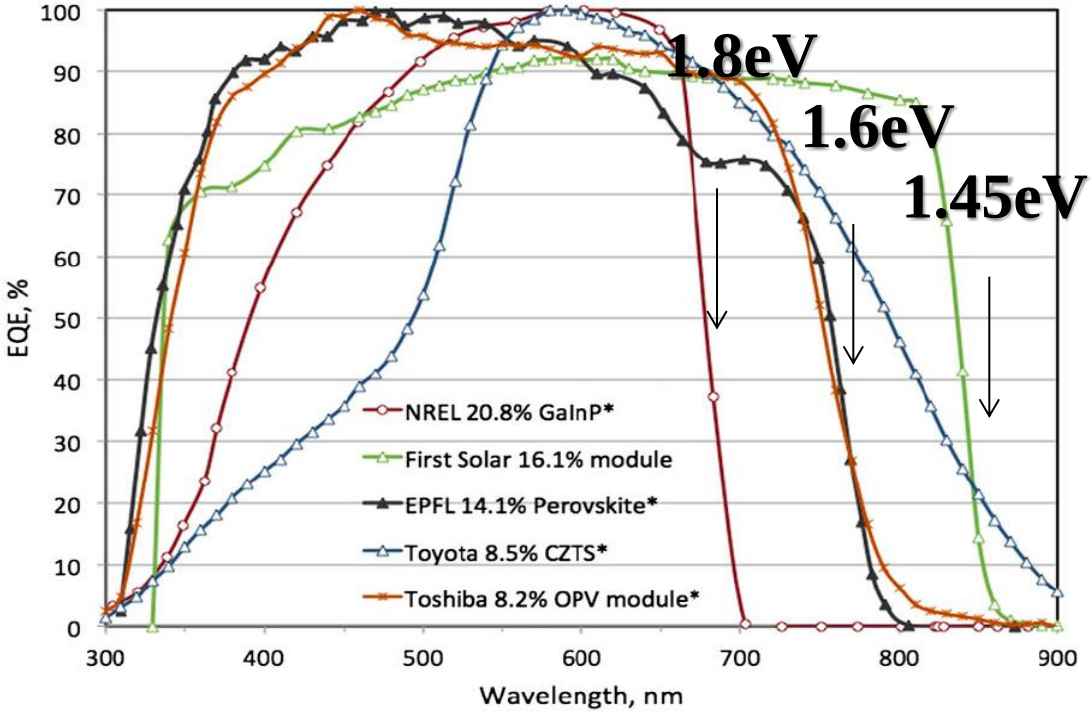

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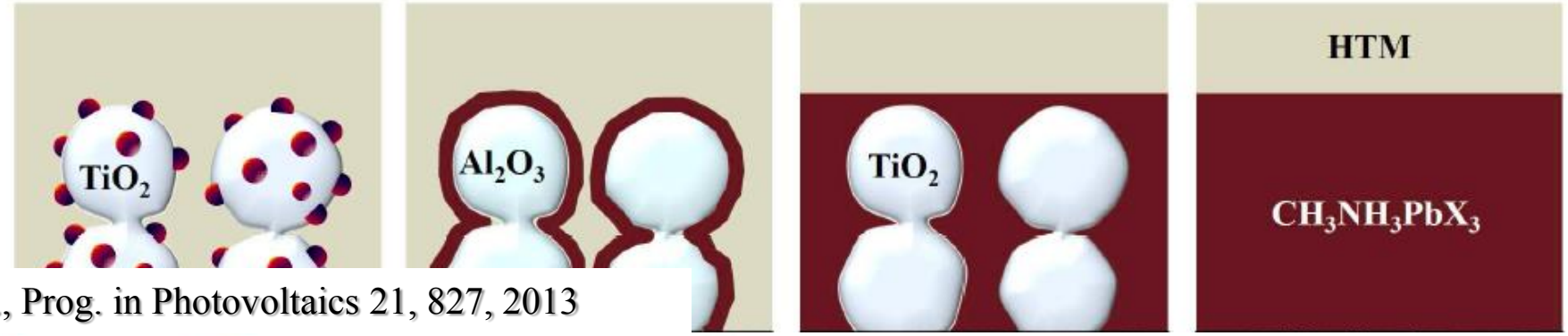

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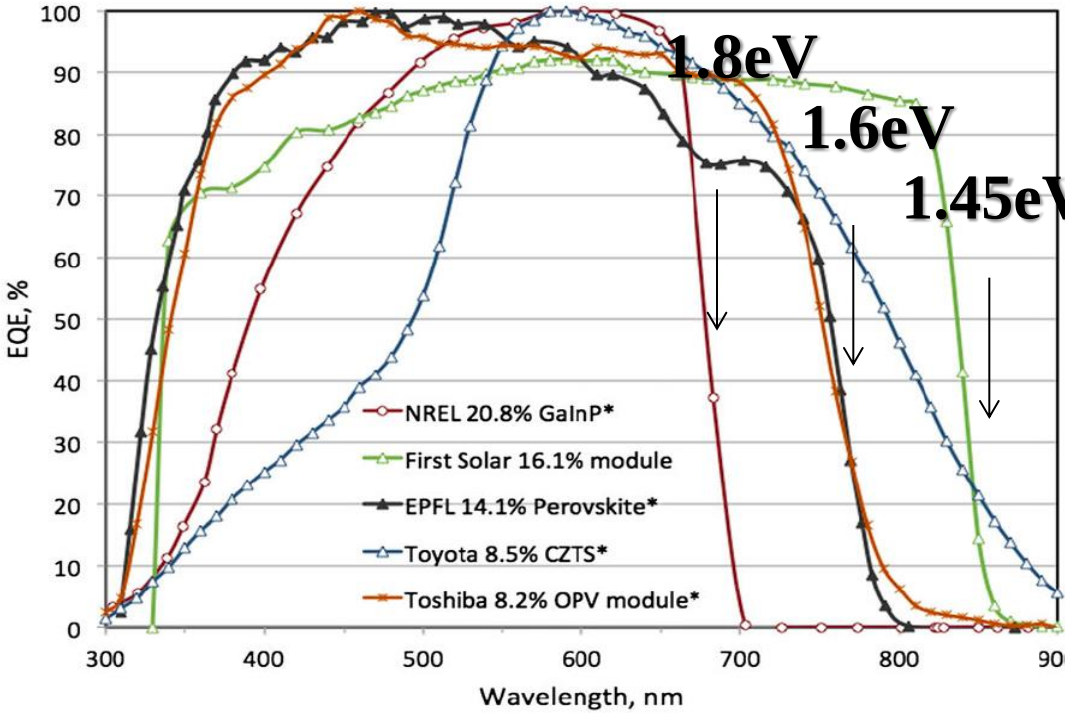

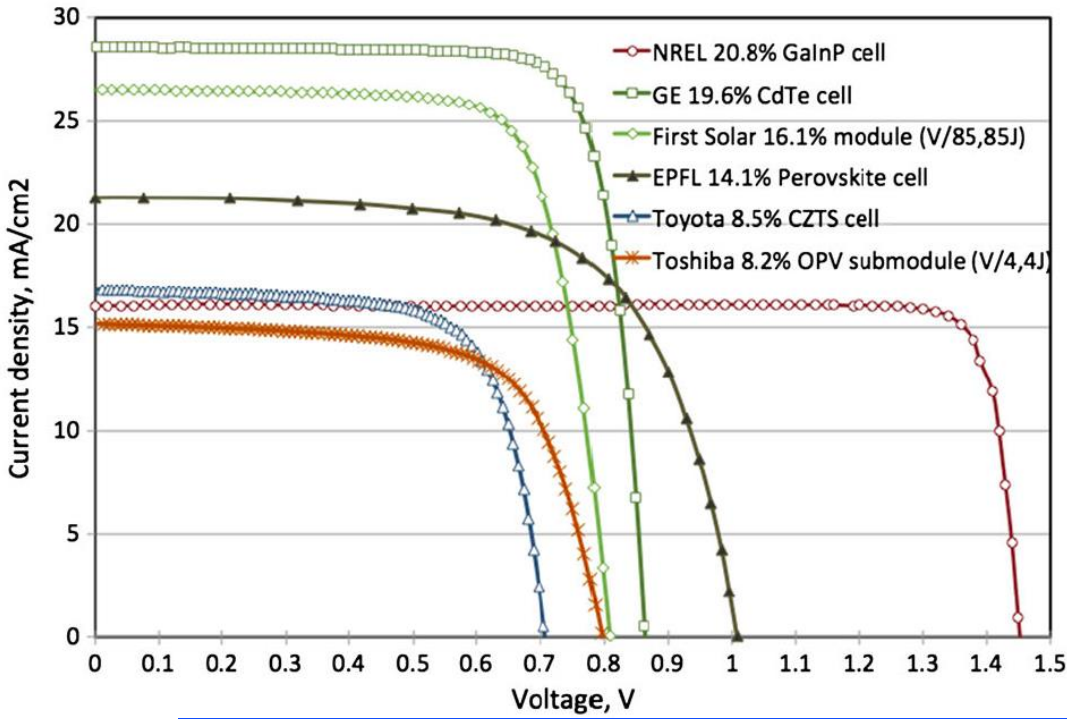

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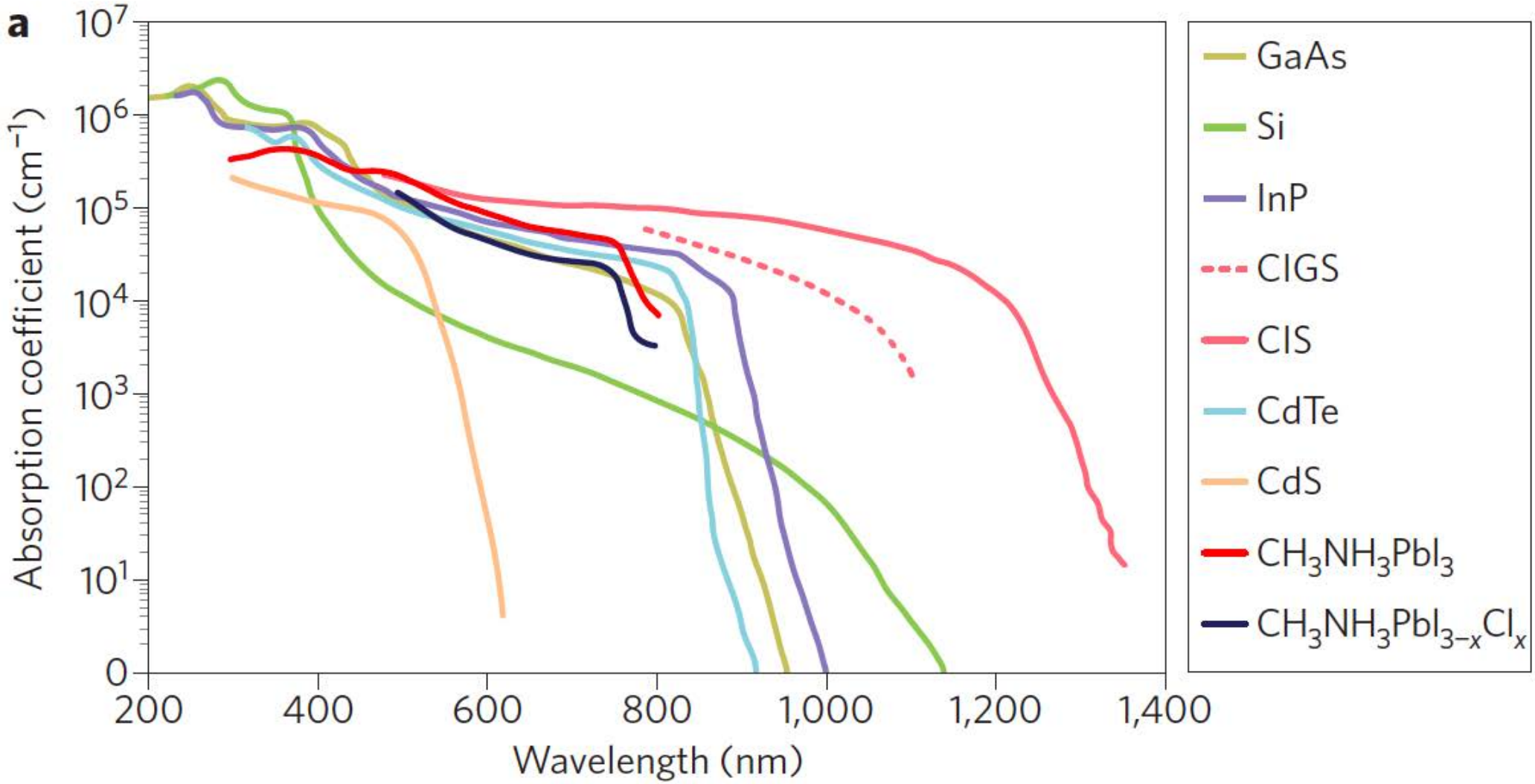
Strong absorption



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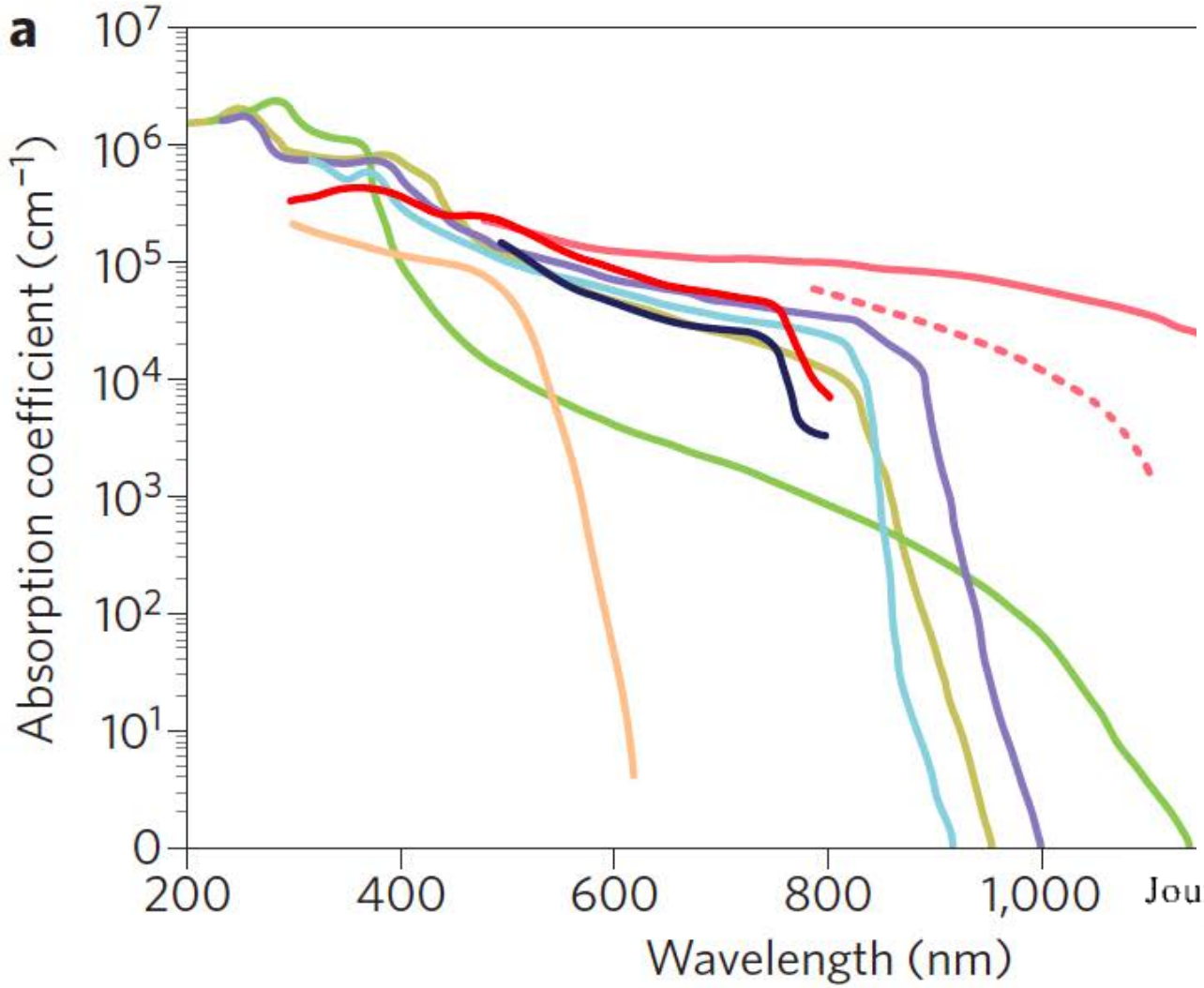
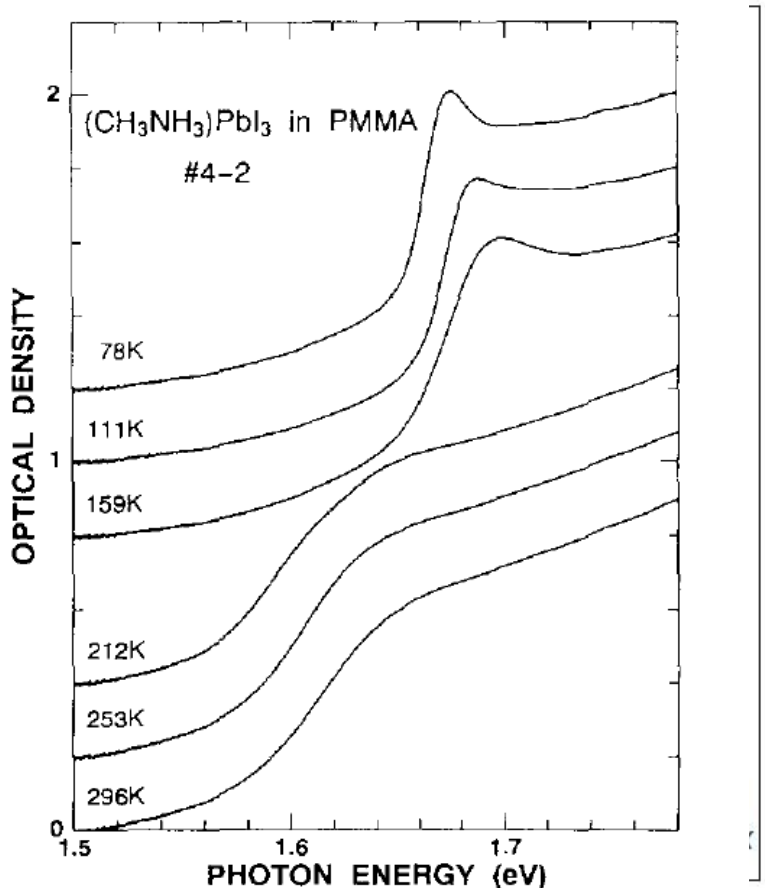




Journal of Luminescence 60&61 (1994) 269 274

Strong absorption

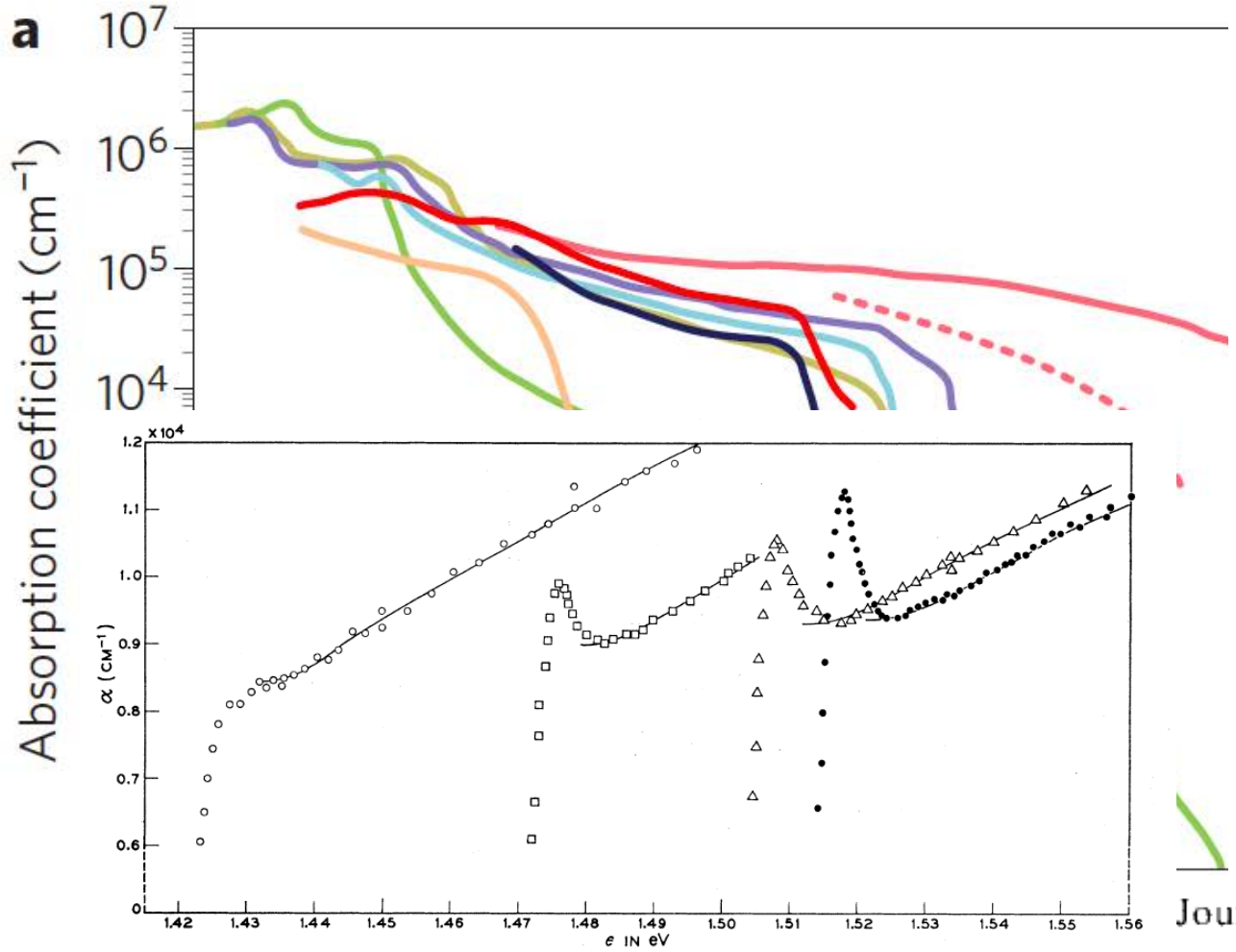
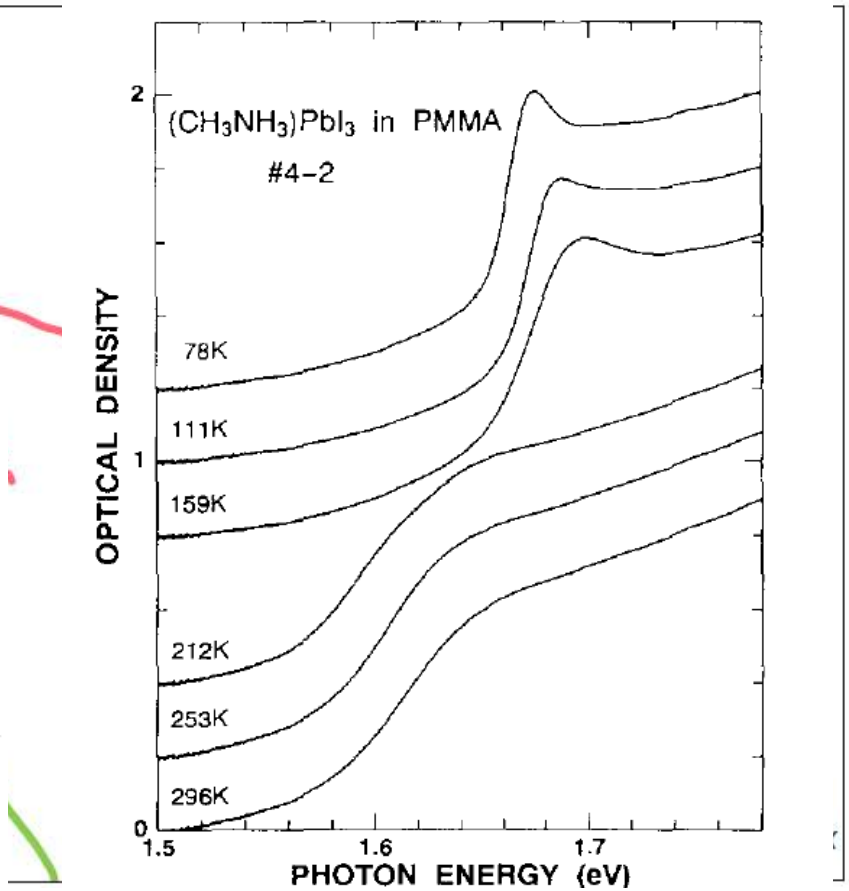


FIG 3 Exciton absorption in GaAs; ○ 294°K, □ 186°K, △90°K, ● 21°K.



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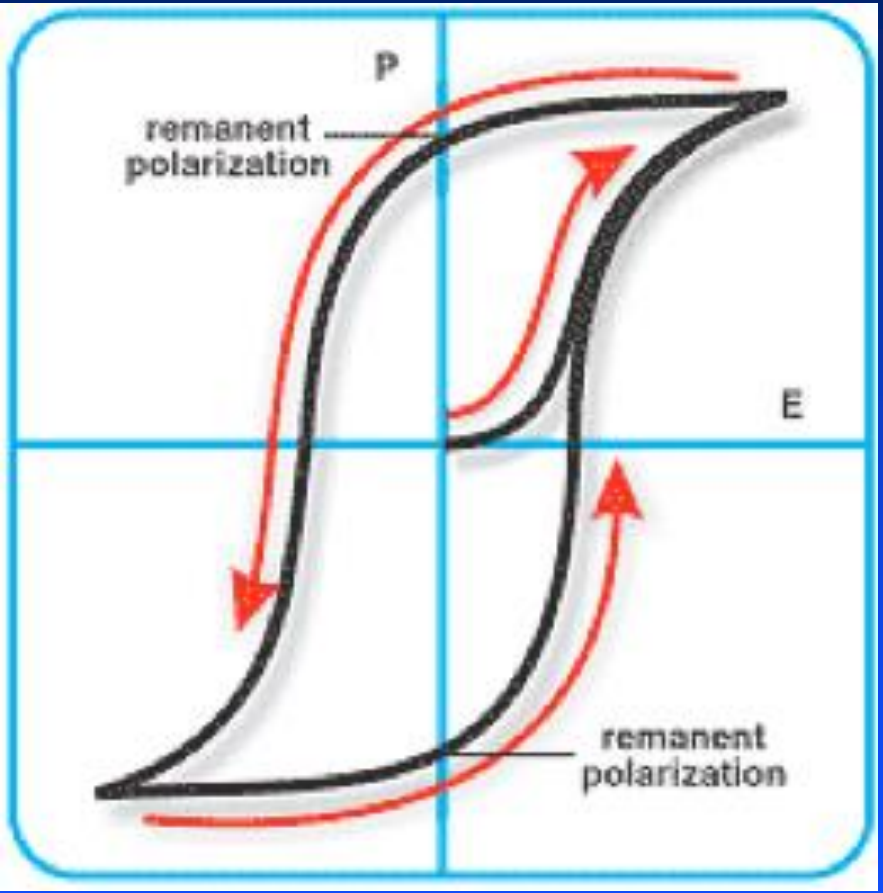
Ferroelectric?



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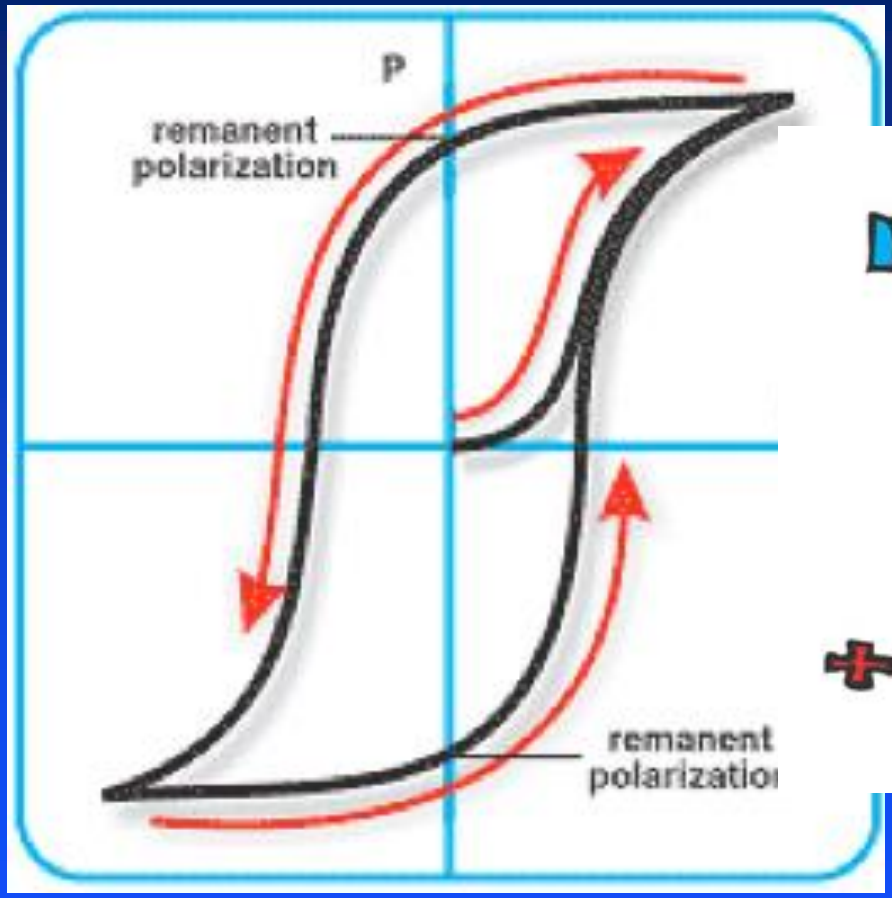

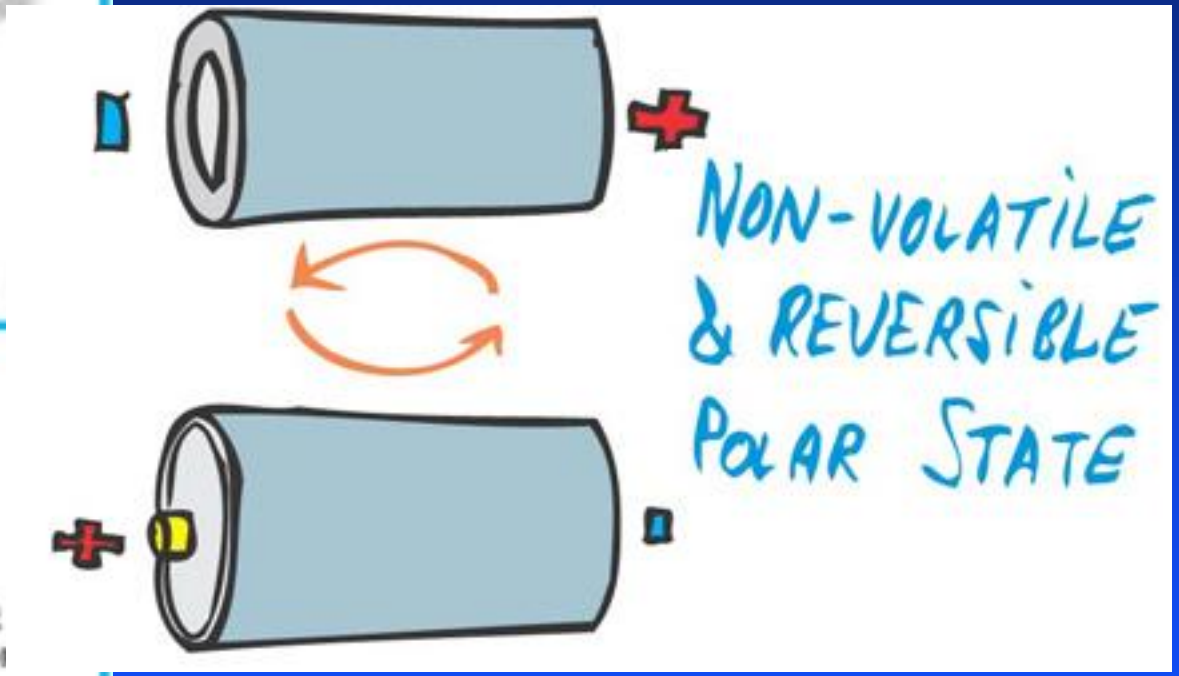

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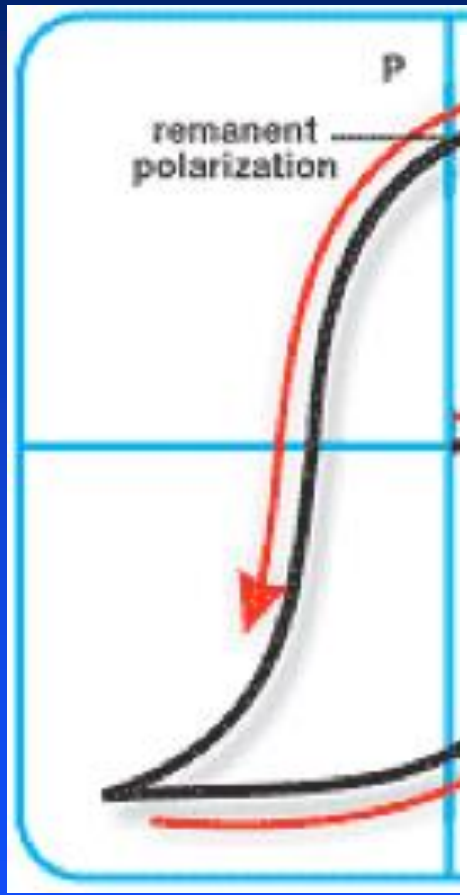
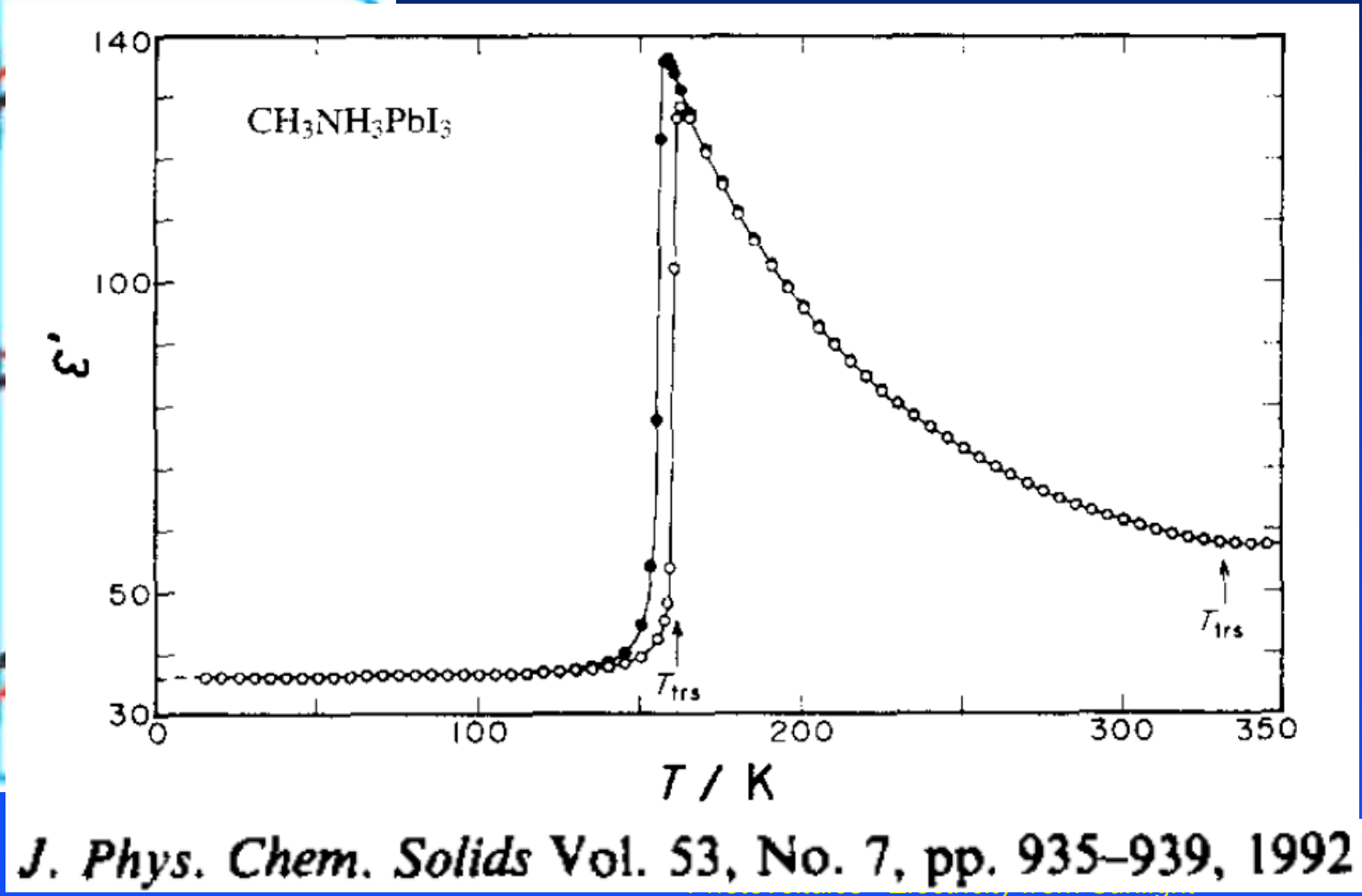
Ferroelectric?





J. Phys. Chem. Solids Vol. 53, No. 7, pp. 935–939, 1992

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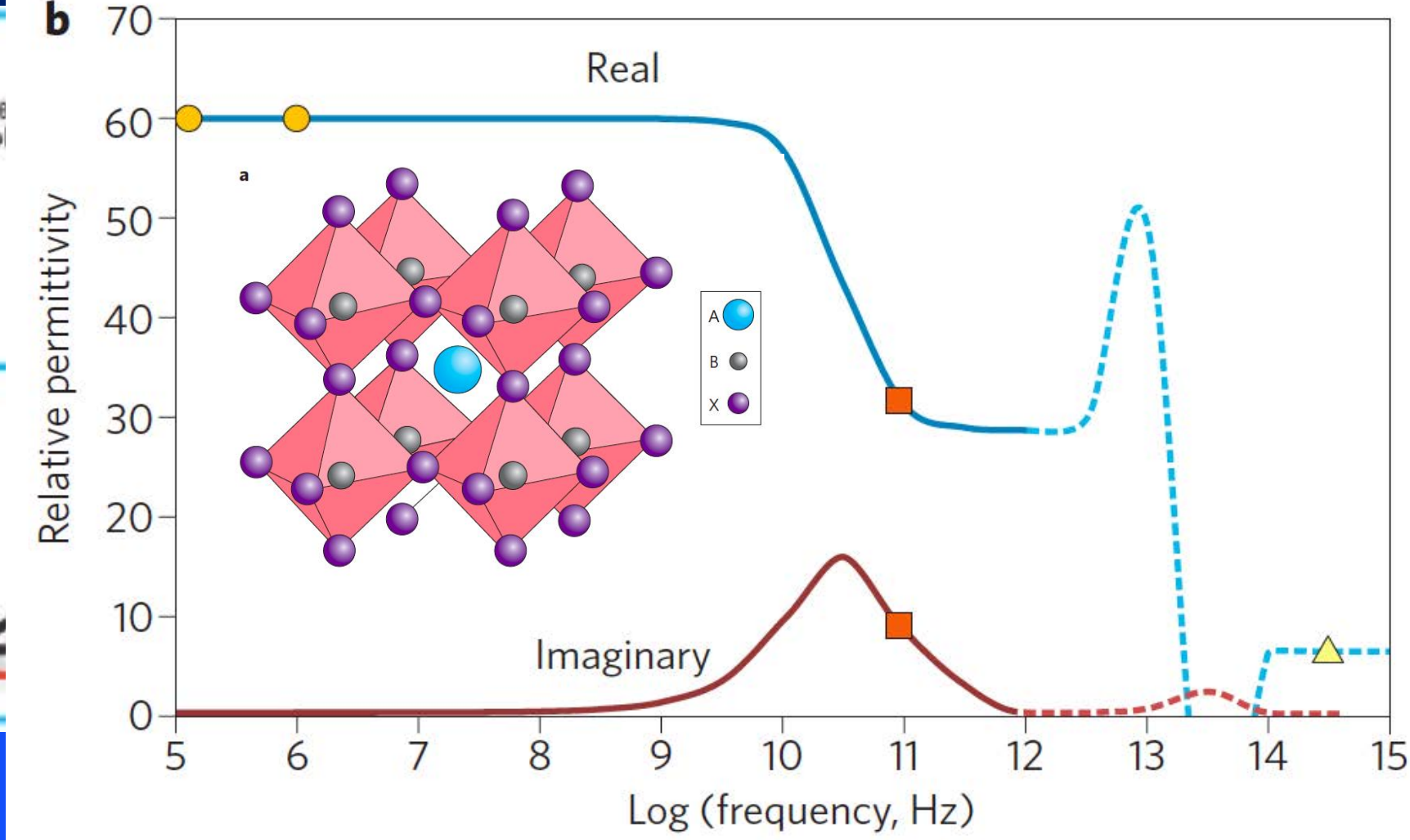
Ferroelectric?



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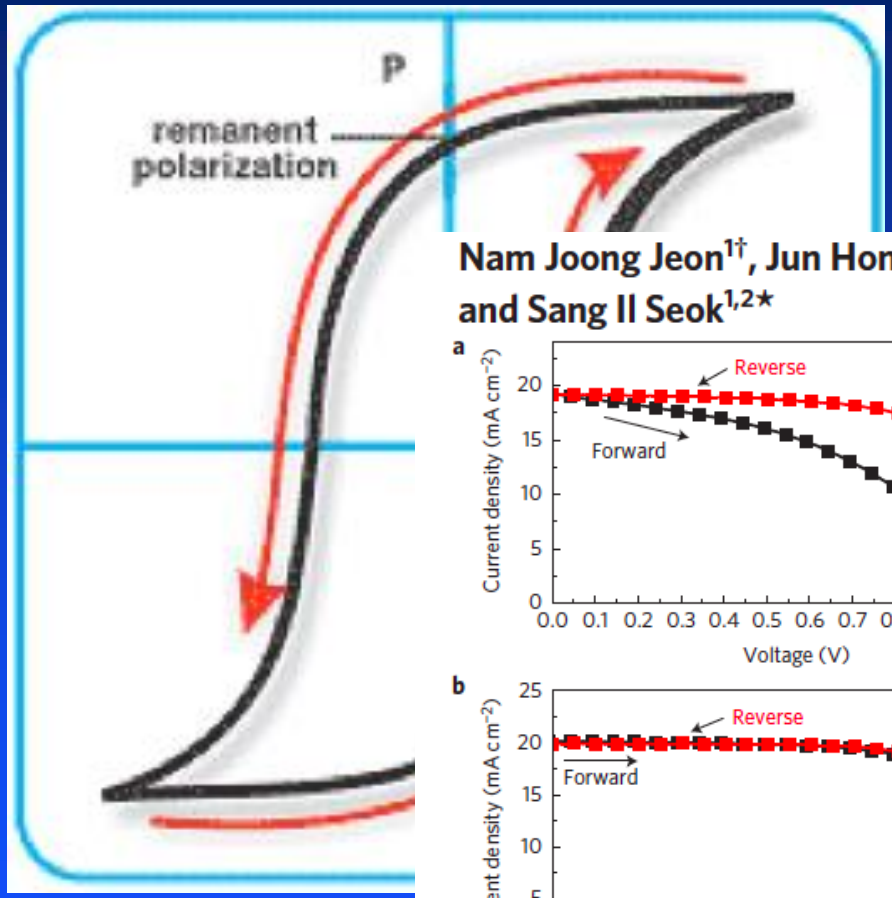
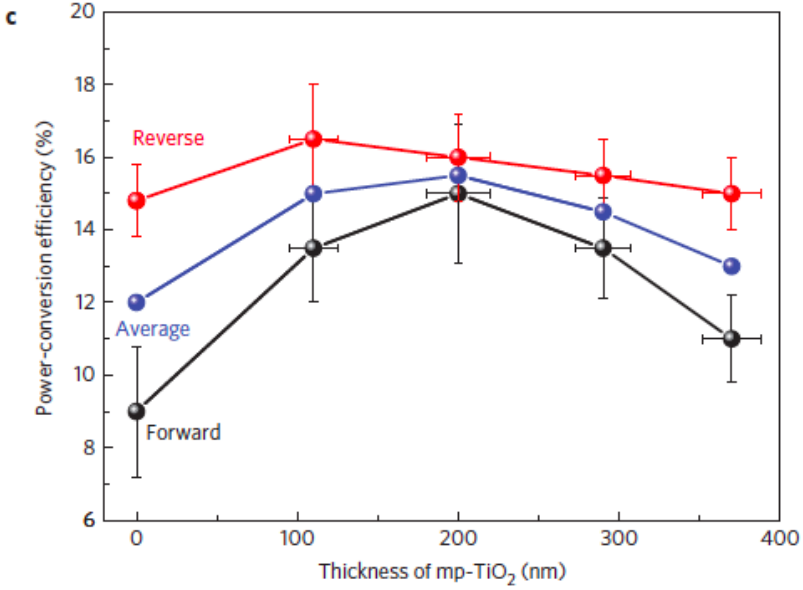
Ferroelectric?



Nam Joong Jeon[1†], Jun Hong Noh[1†], Young Chan Kim[1], Woon Seok Yang[1], Seungchan Ryu[1] and Sang Il Seok[1,2★]



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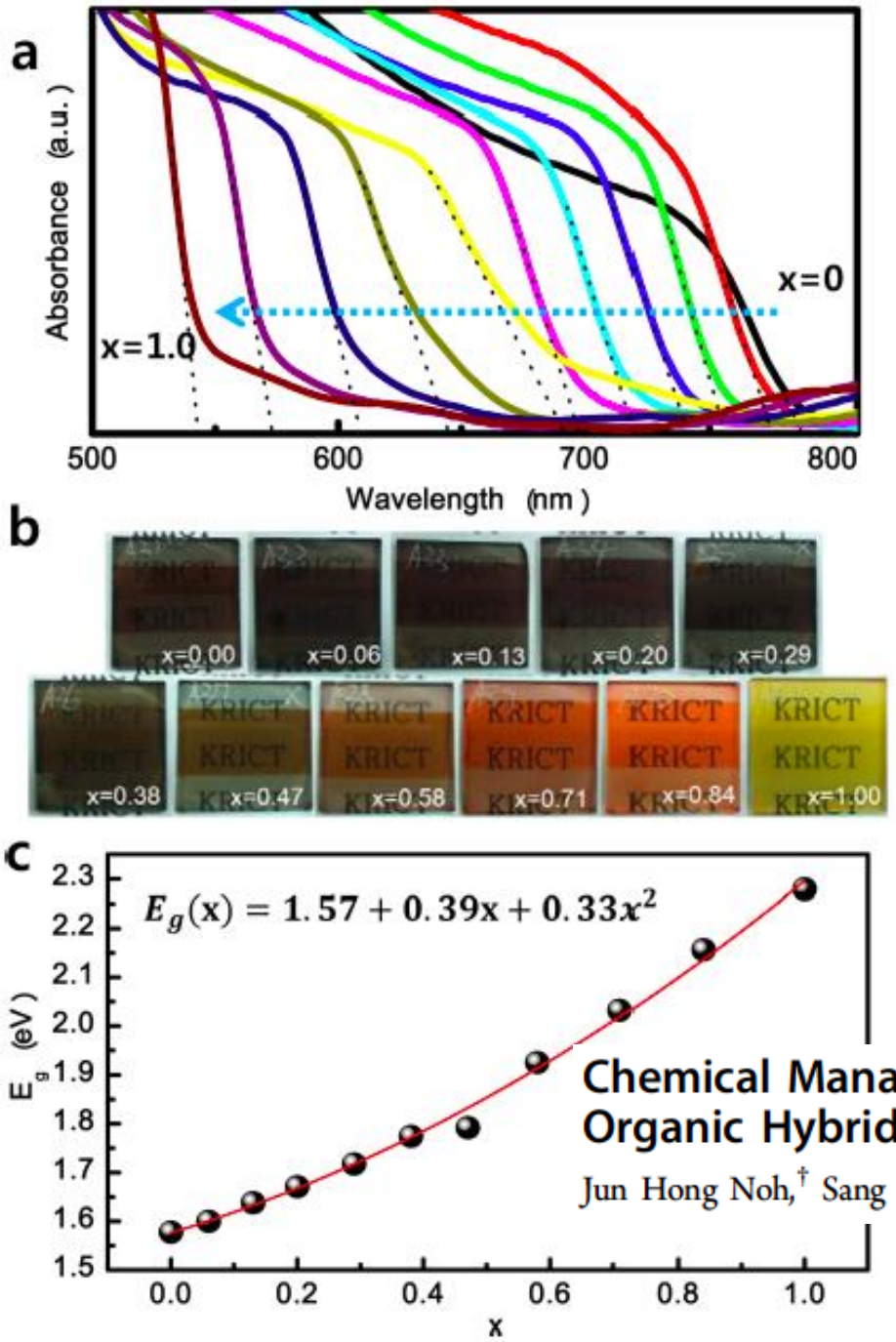
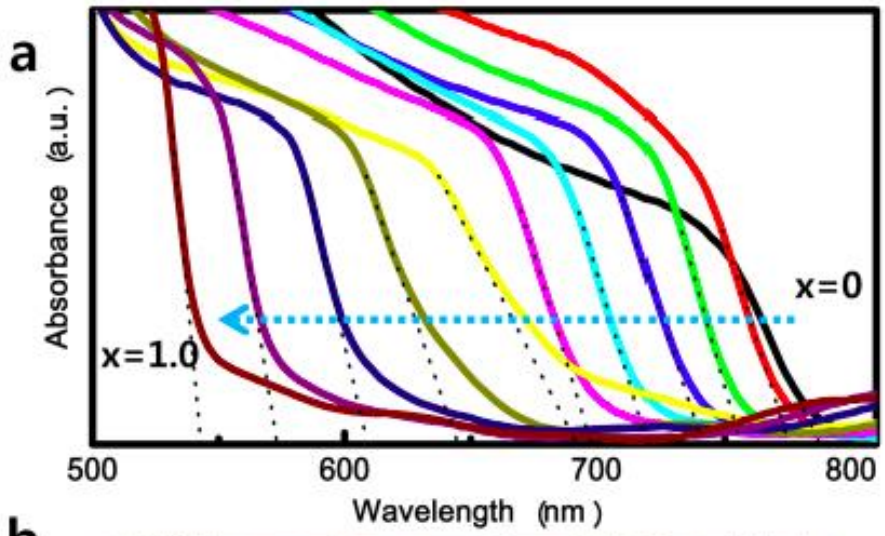
Mixed compounds

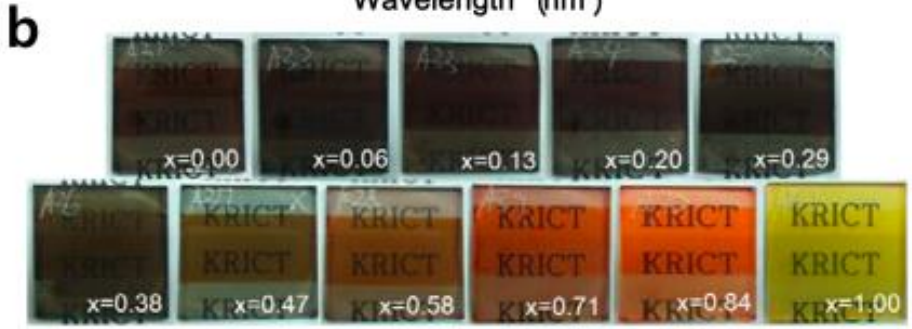
$$MAPb(I_{1-x}Br_x)_3$$

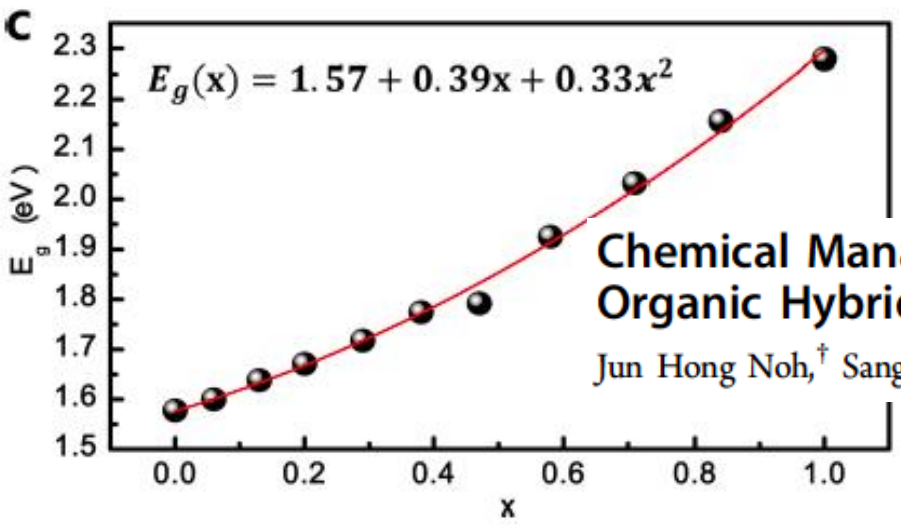


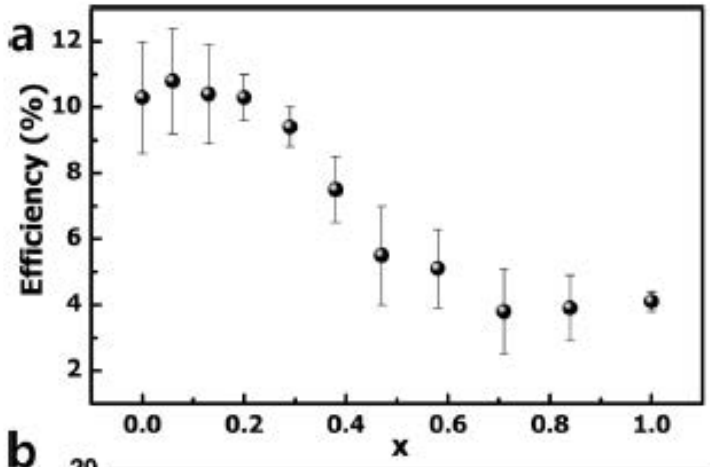
Chemical Management for Colorful, Efficient, and Stable Inorganic–Organic Hybrid Nanostructured Solar Cells

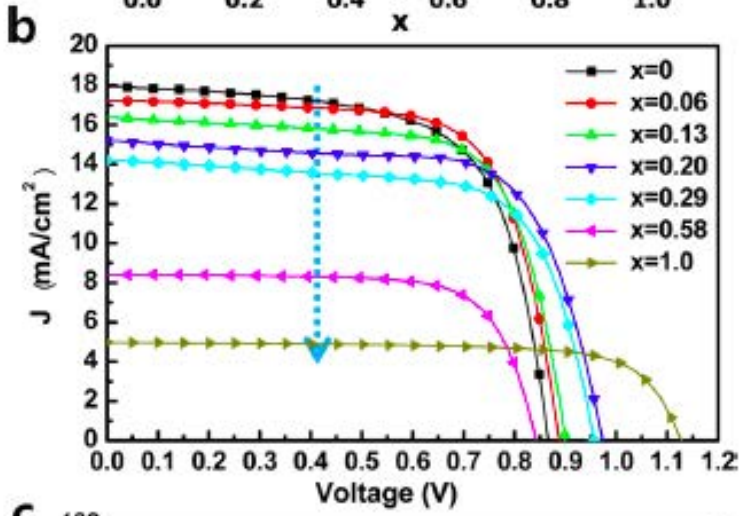
Jun Hong Noh,[†] Sang Hyuk Im,[‡] Jin Hyuck Heo,[†] Tarak N. Mandal,[†] and Sang Il Seok*[,†,§]

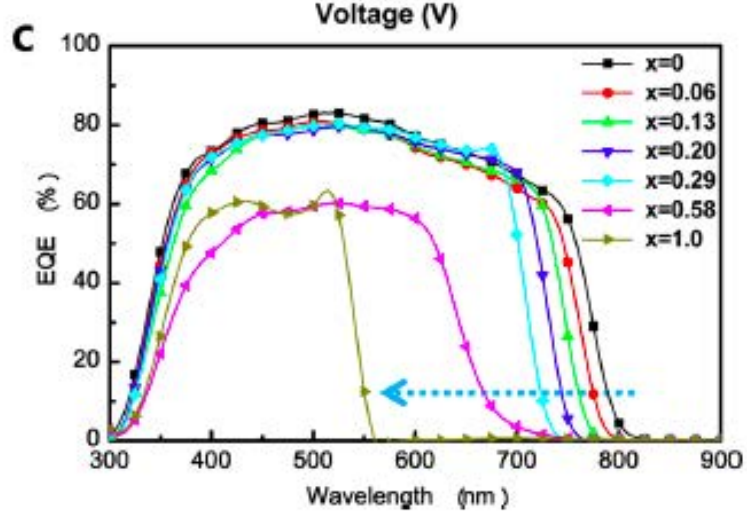












Chemical Management
Organic Hybrid Nanost

Jun Hong Noh,† Sang Hyuk Im,‡ J

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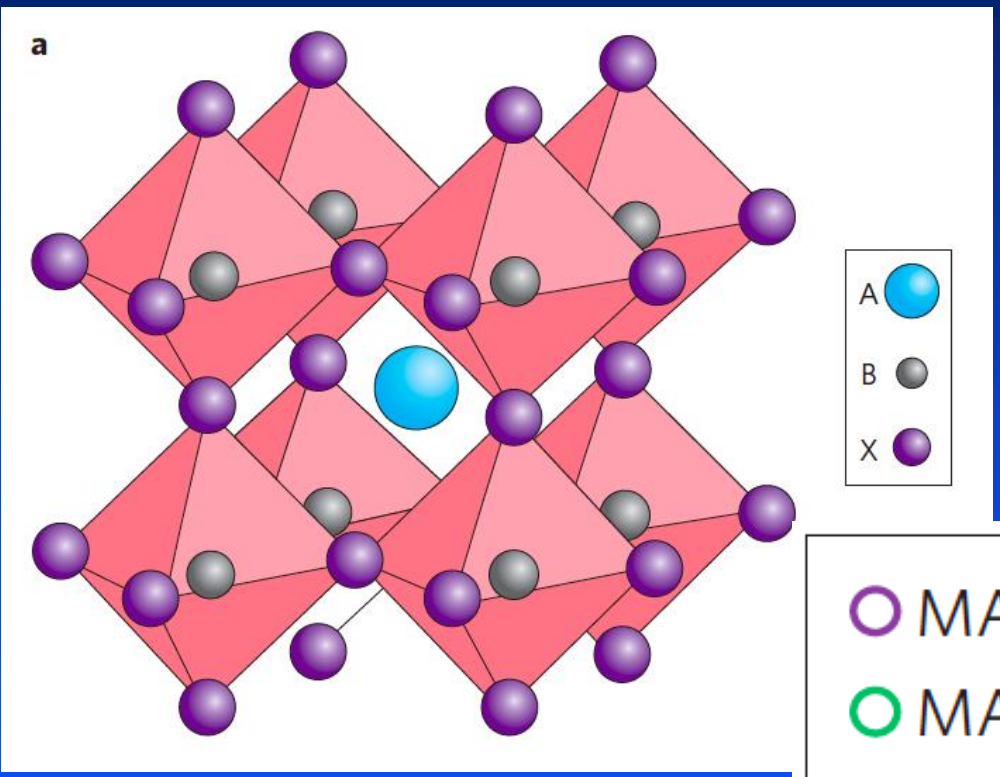
Mixed compounds



○ $MAPbI_3$	□ $MAPbBr_3$	◇ $MAPbCl_3$
○ $MASnI_3$	□ $MASnBr_3$	◇ $MASnCl_3$
× $EAPbI_3$	+ $EAPbBr_3$	✳ $EAPbCl_3$
× $EASnI_3$	+ $EASnBr_3$	✳ $EASnCl_3$

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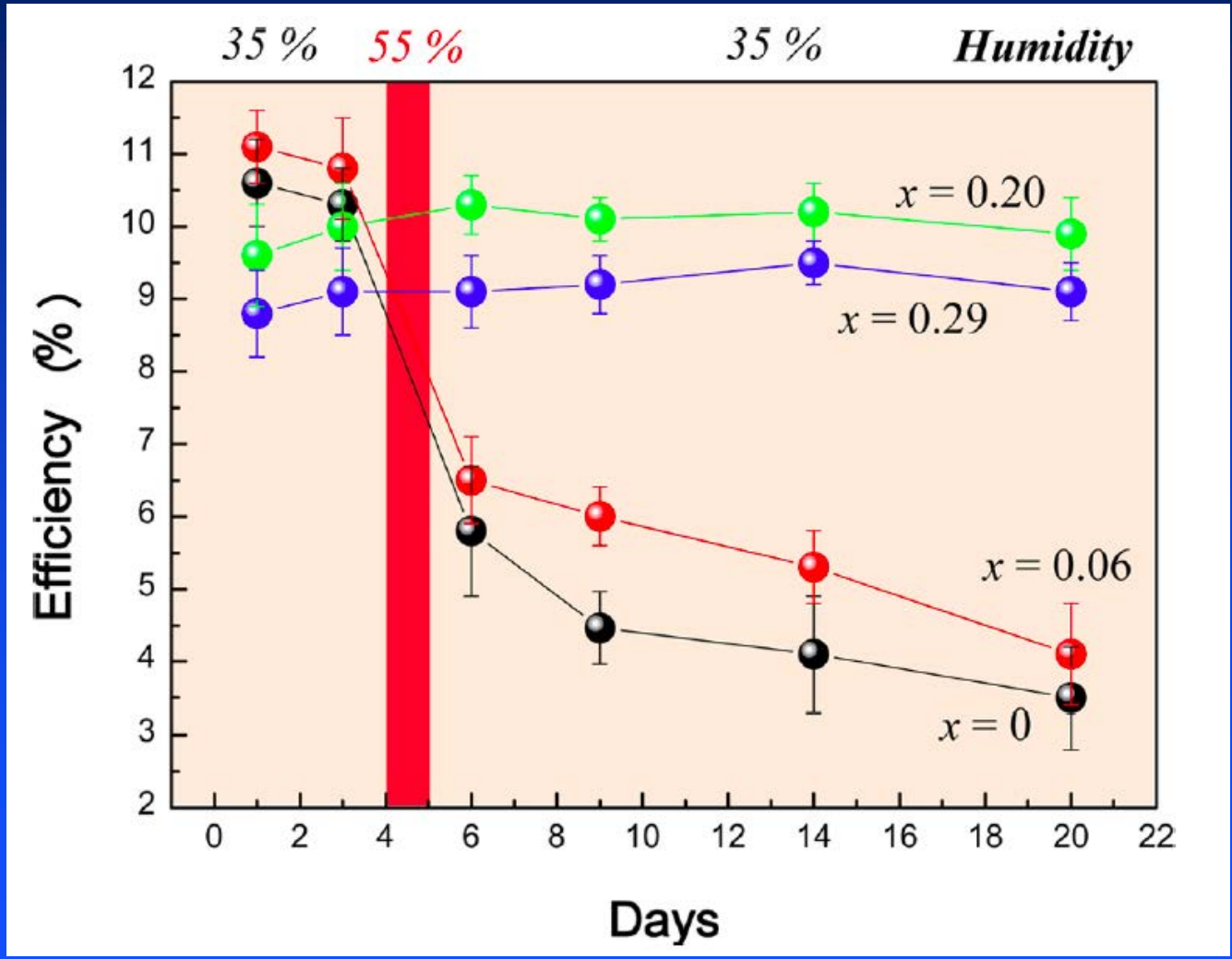
Stability

$$MAPb(I_{1-x}Br_x)_3$$



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Manufacturing costs

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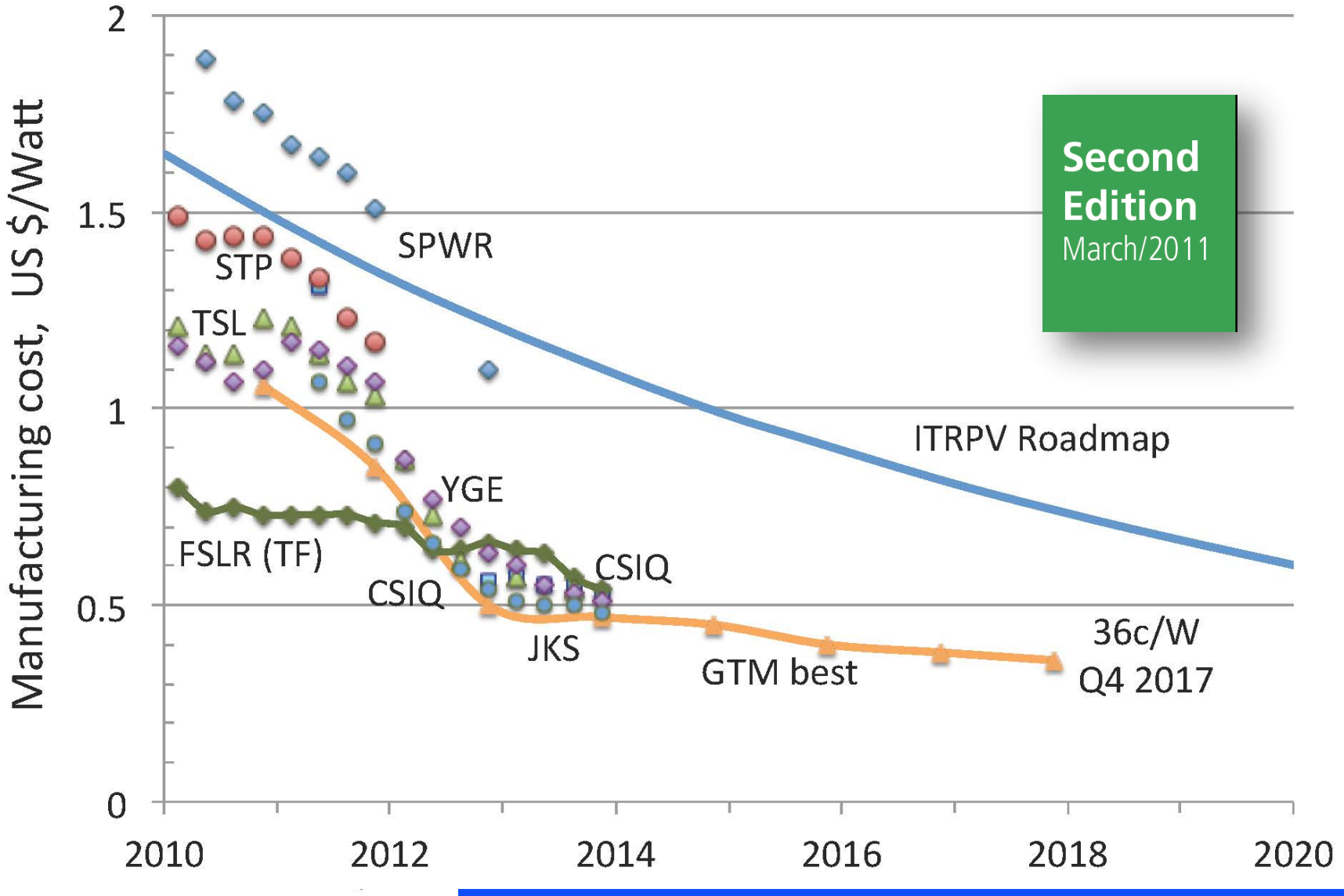

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Manufacturing costs

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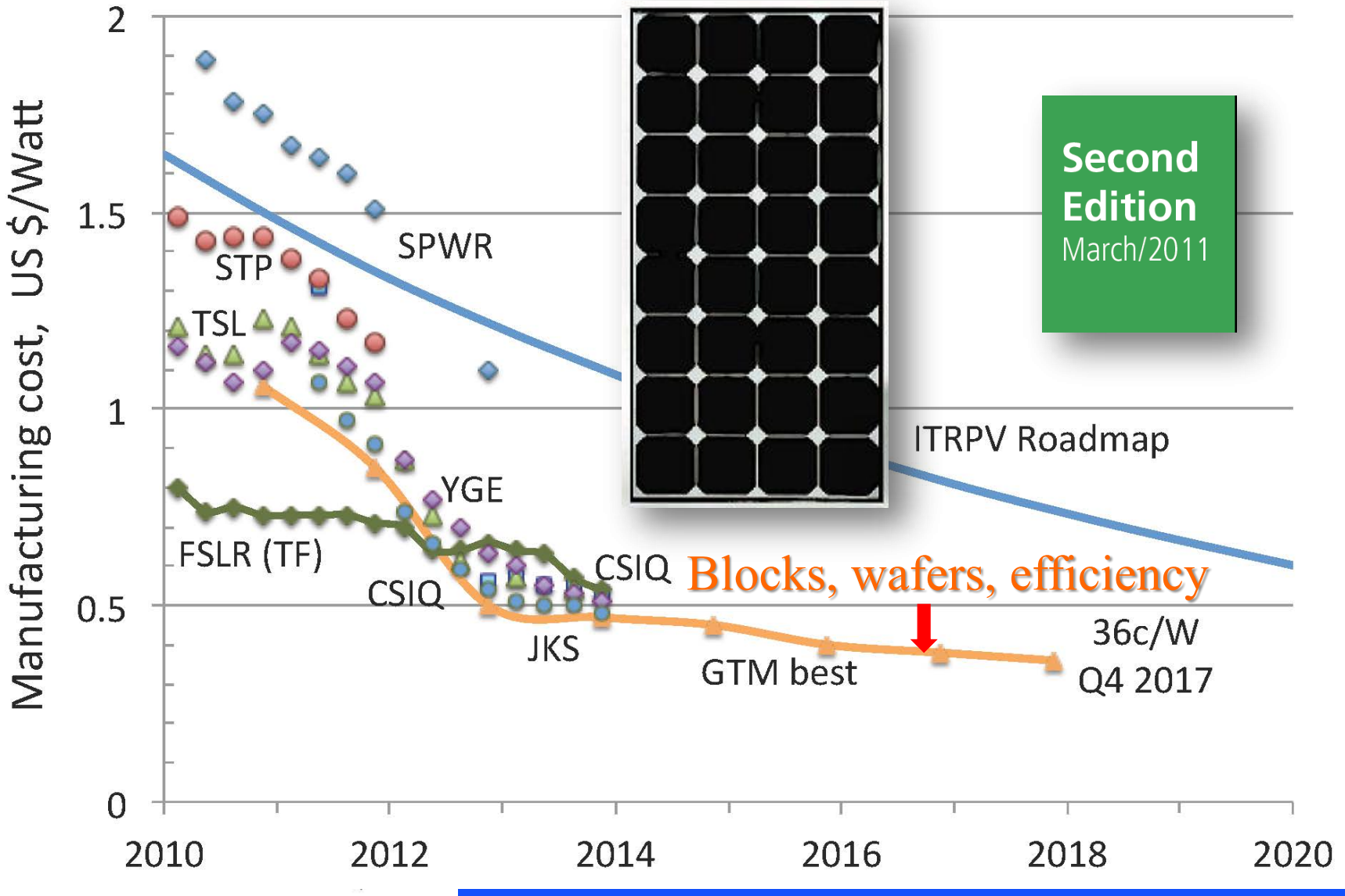

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Manufacturing costs

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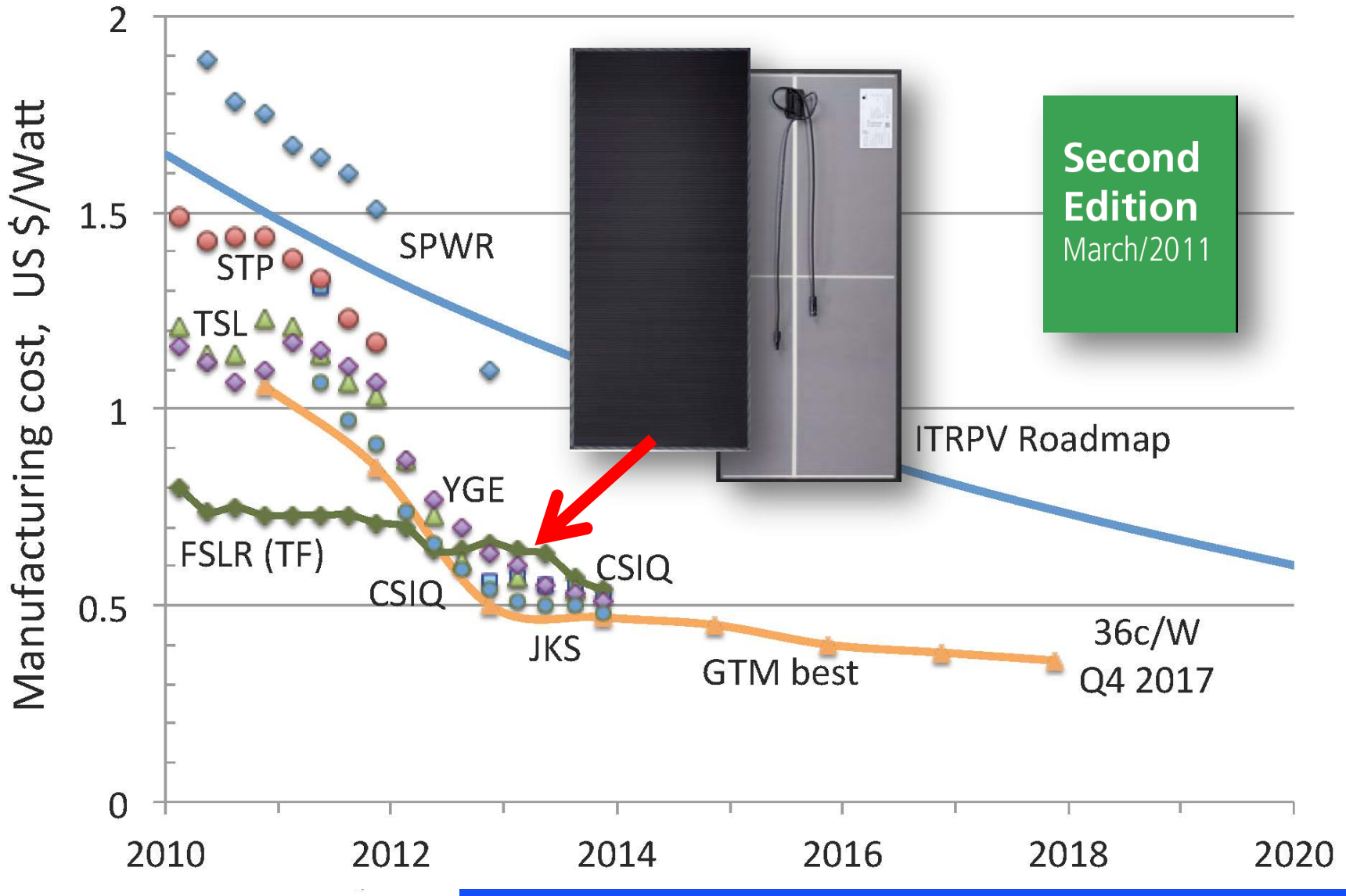

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Manufacturing costs

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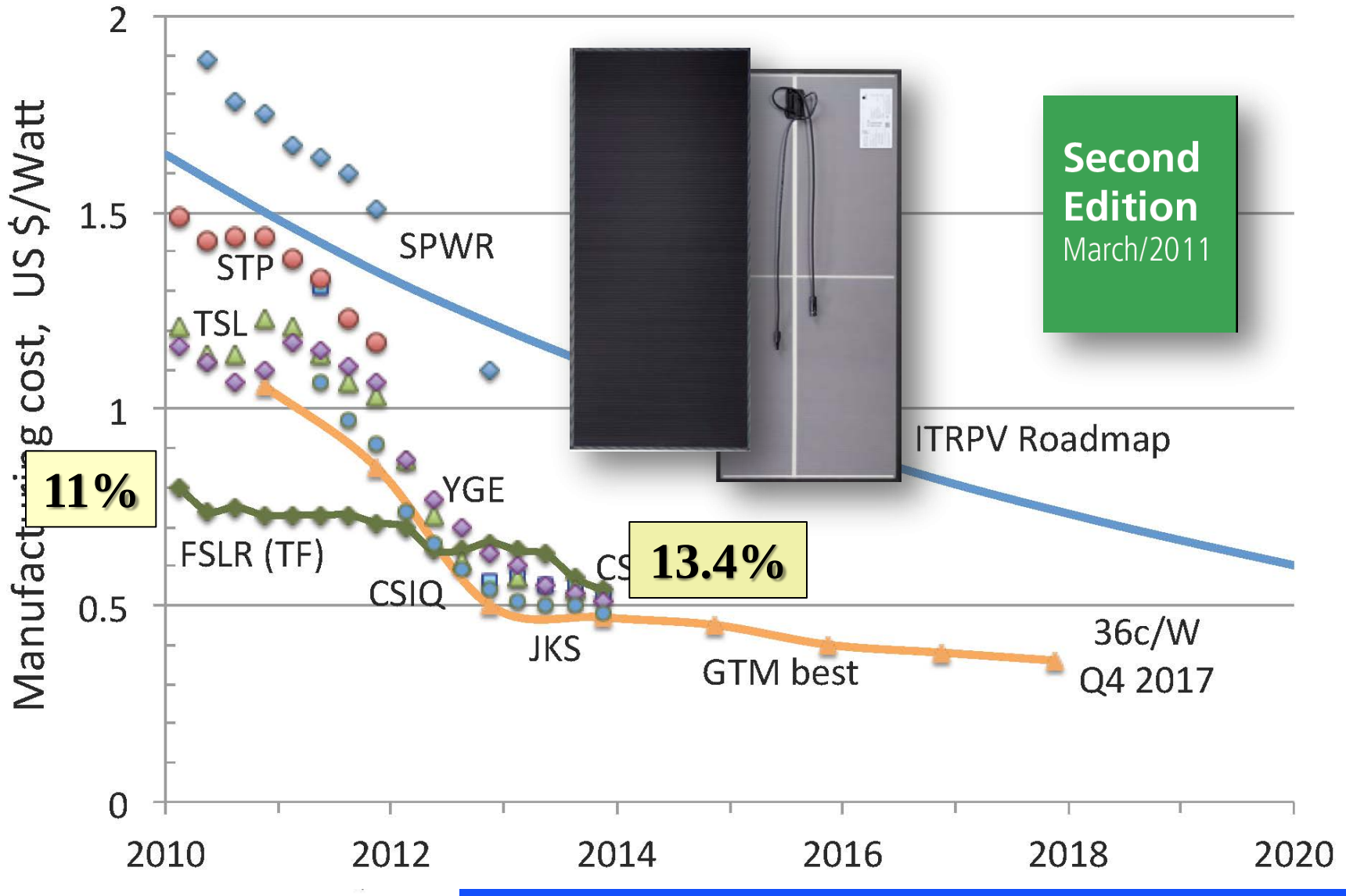
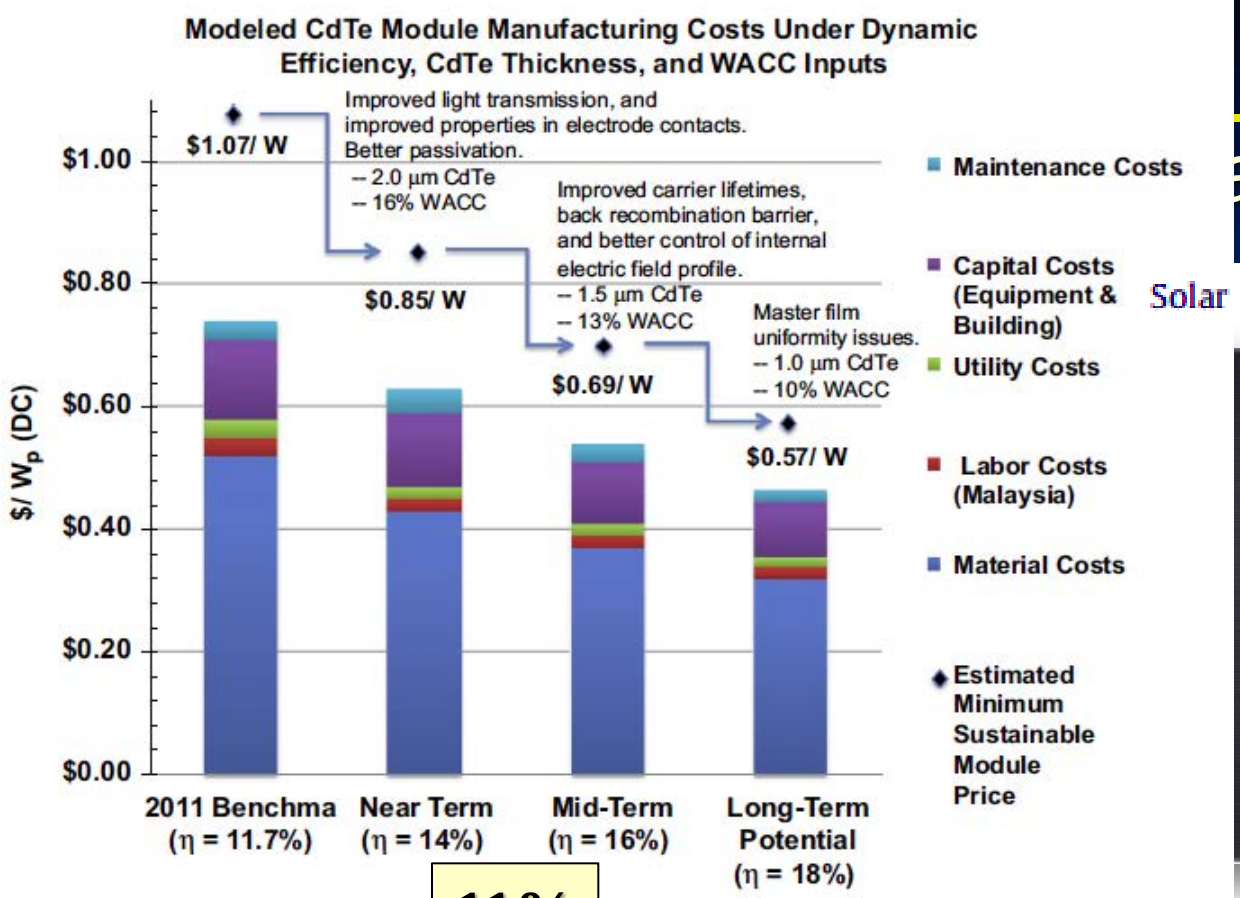


anufacturing costs



Solar Energy Materials & Solar Cells 115 (2013) 199–212

Second Edition
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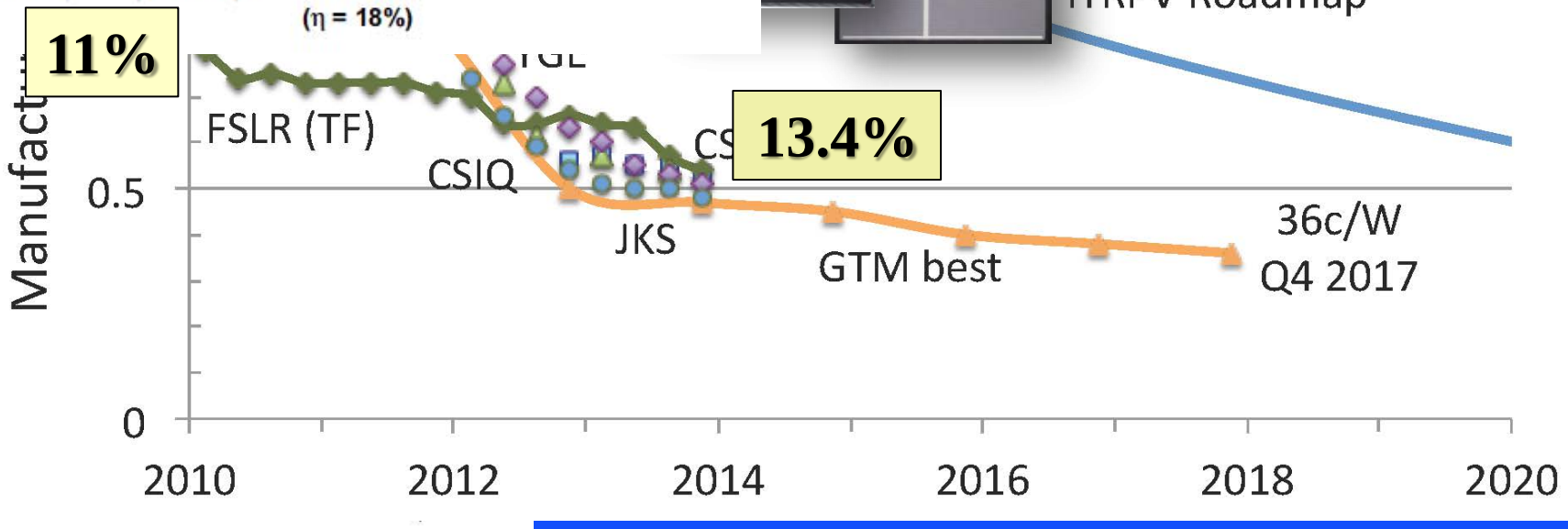

Third Edition March/2012

Manufacturing costs

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Third Edition March/2012

Manufacturing costs

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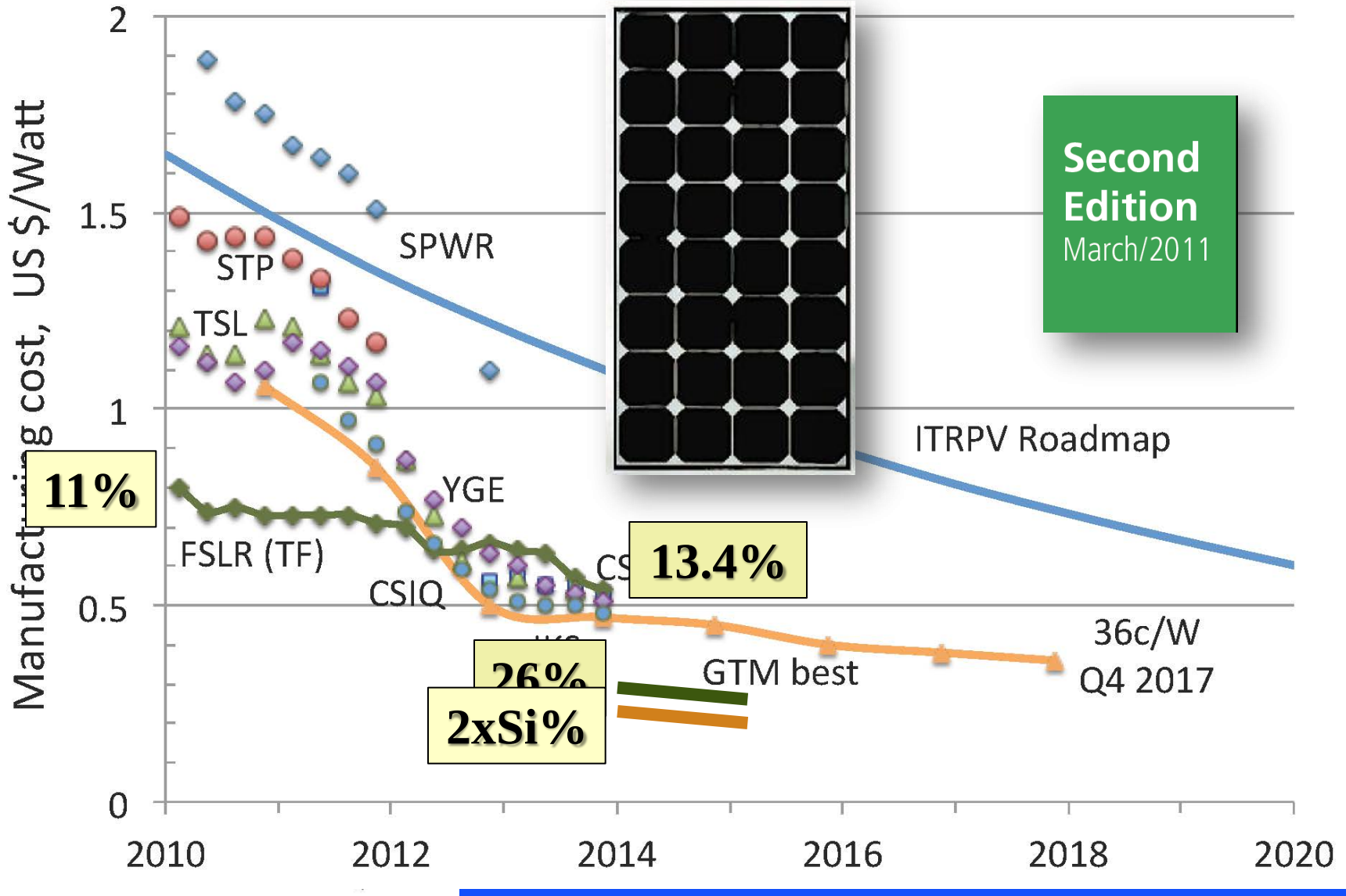
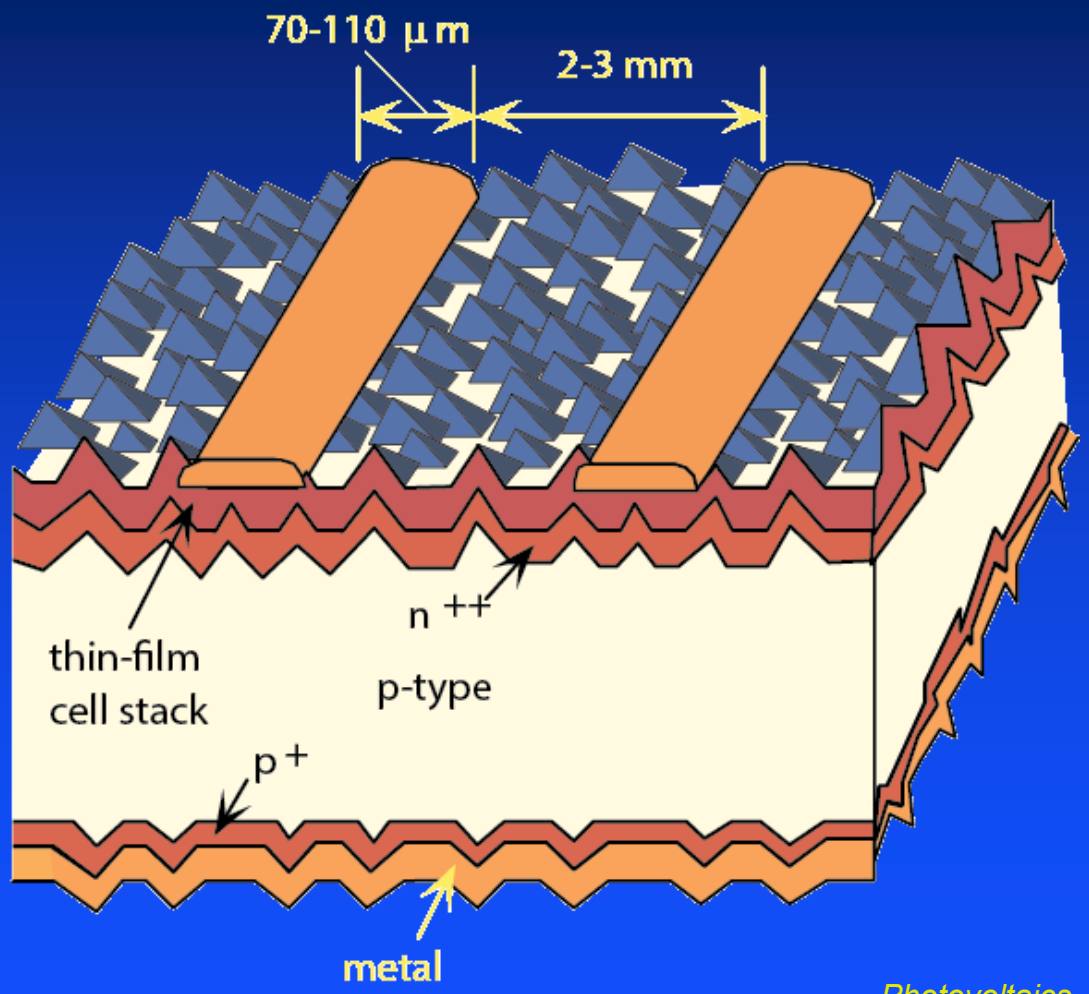
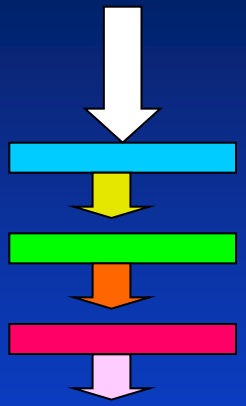


Si wafer-based stack: ultimate solution?

more sophisticated "active" AR coat?





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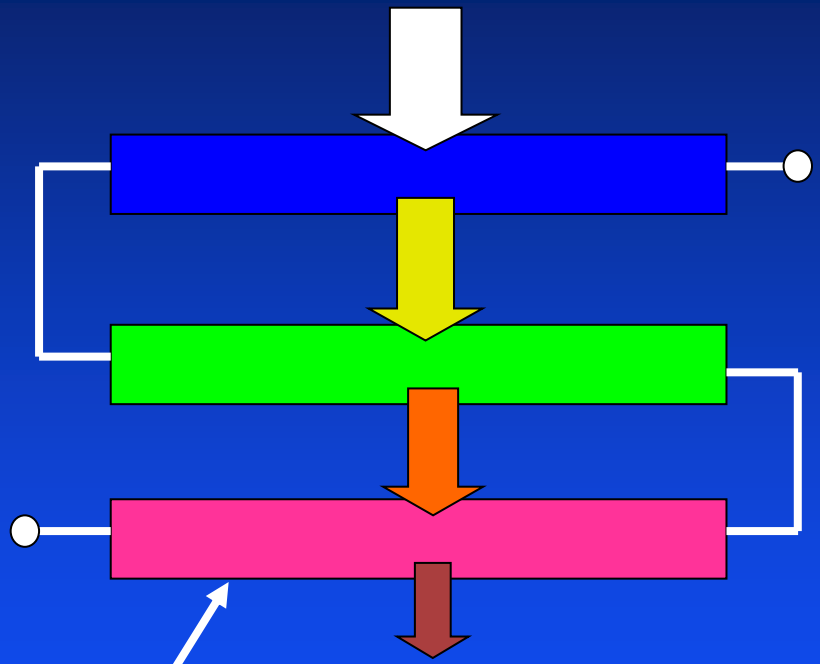
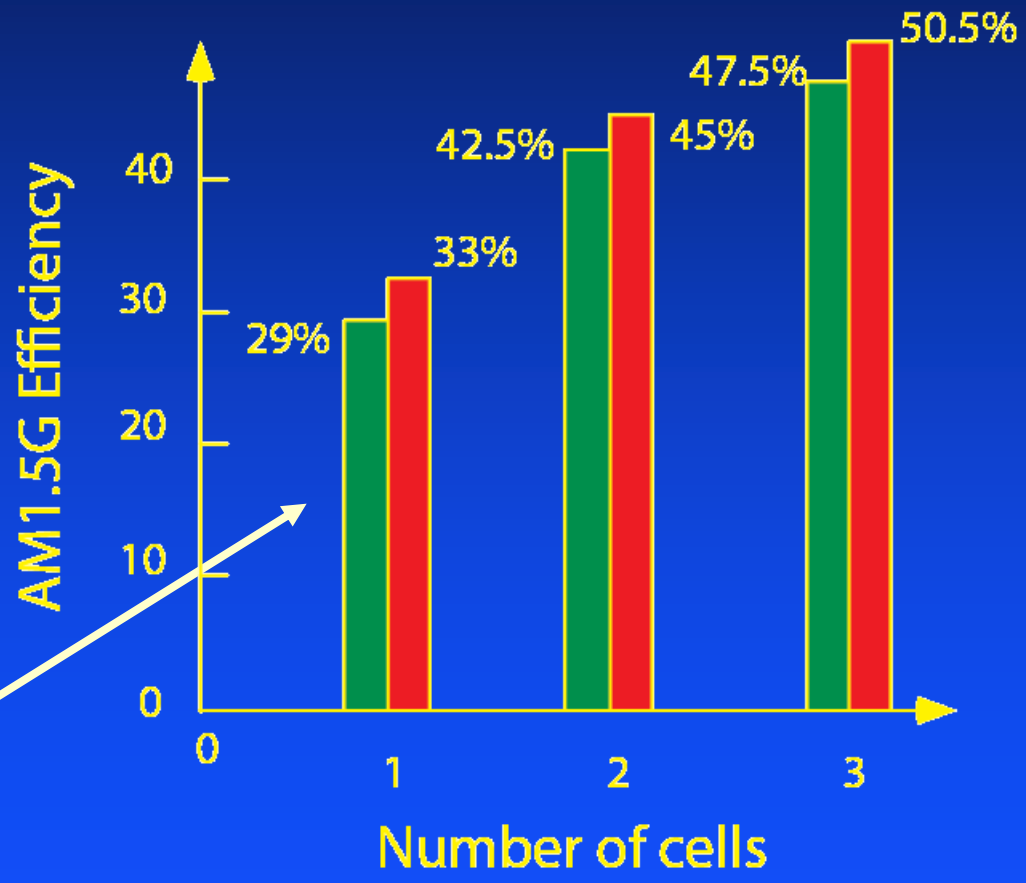
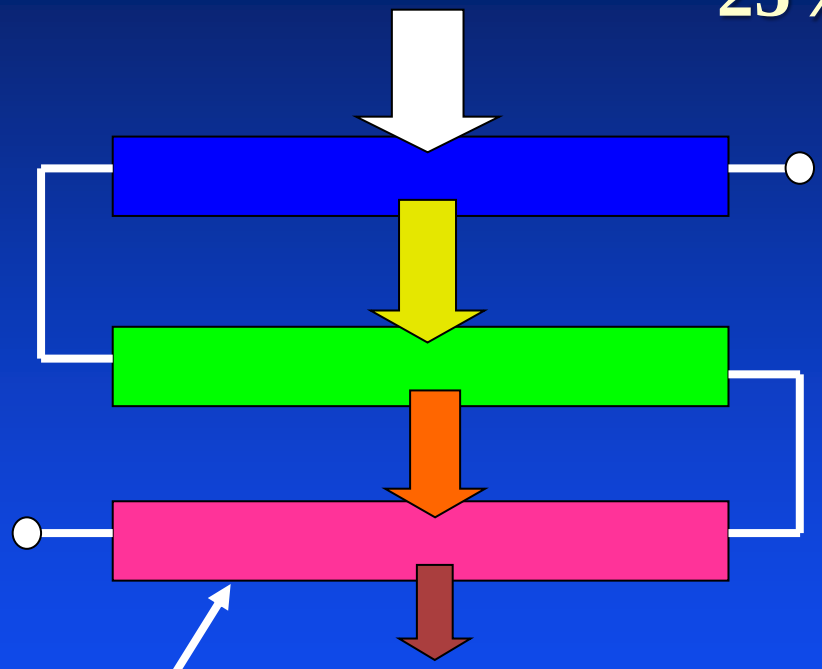
c-Si tandem



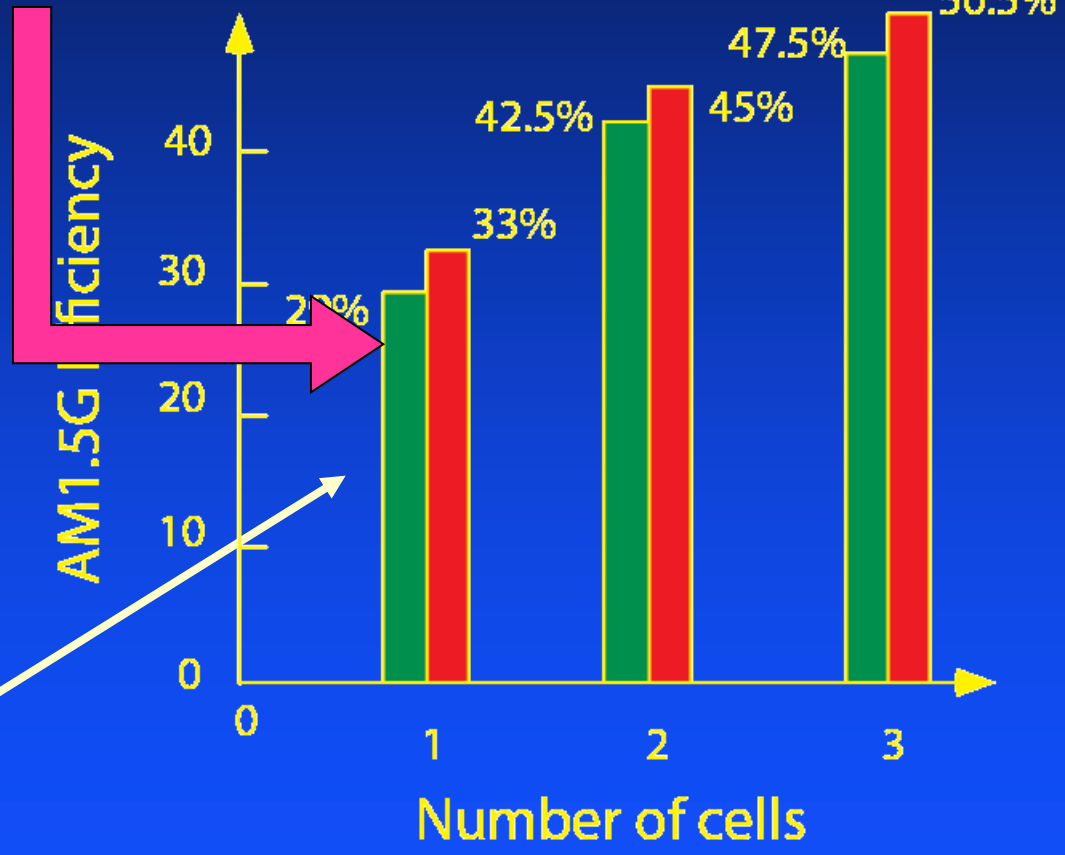
Free choice or Si



c-Si tandem



Free choice or Si



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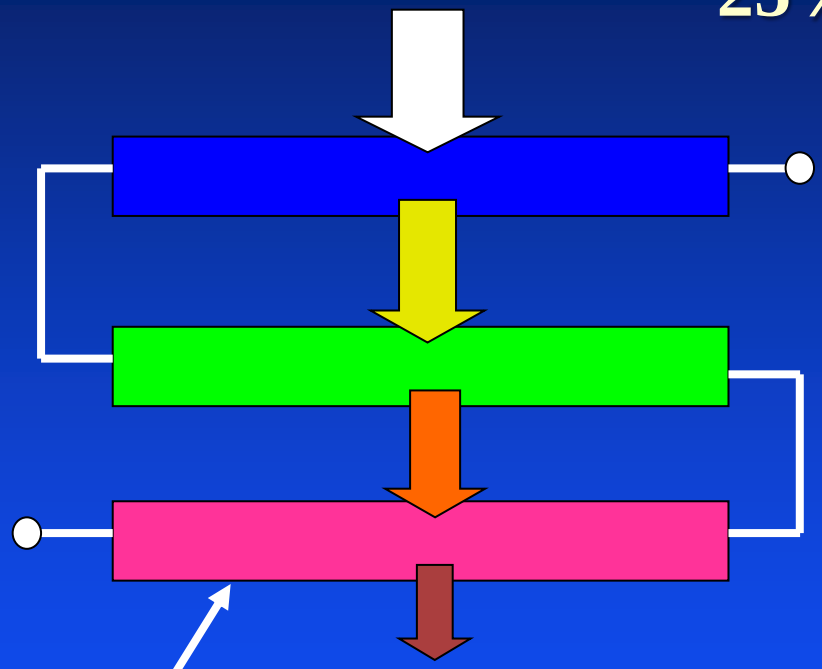
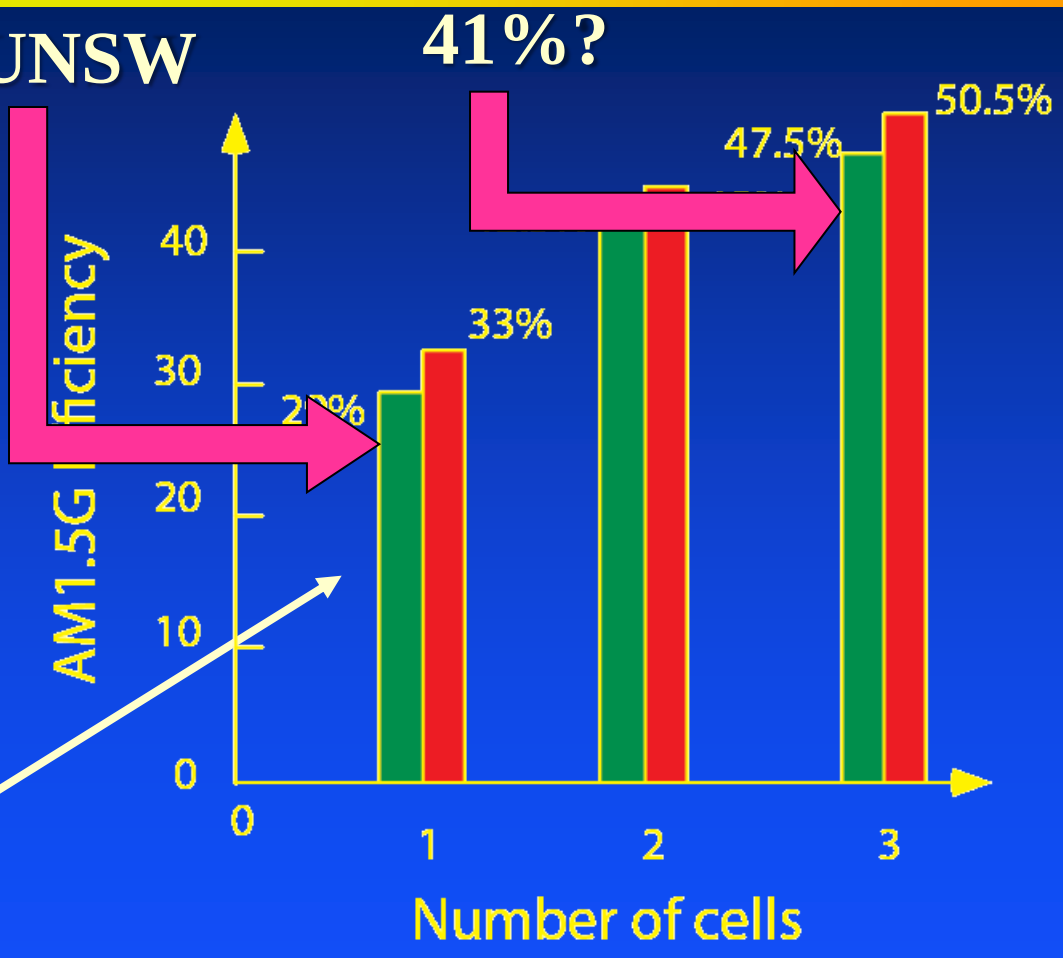
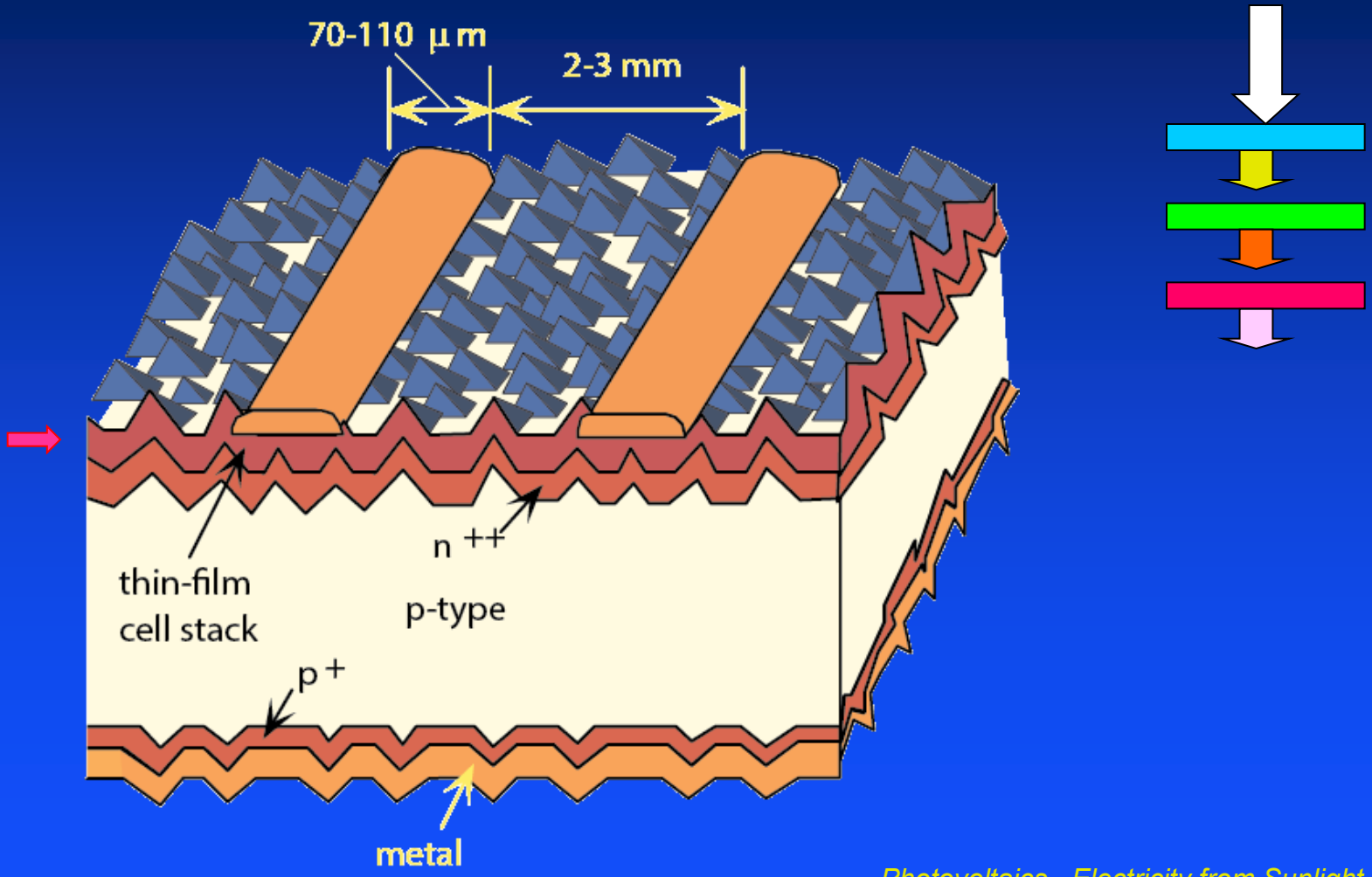
c-Si tandem



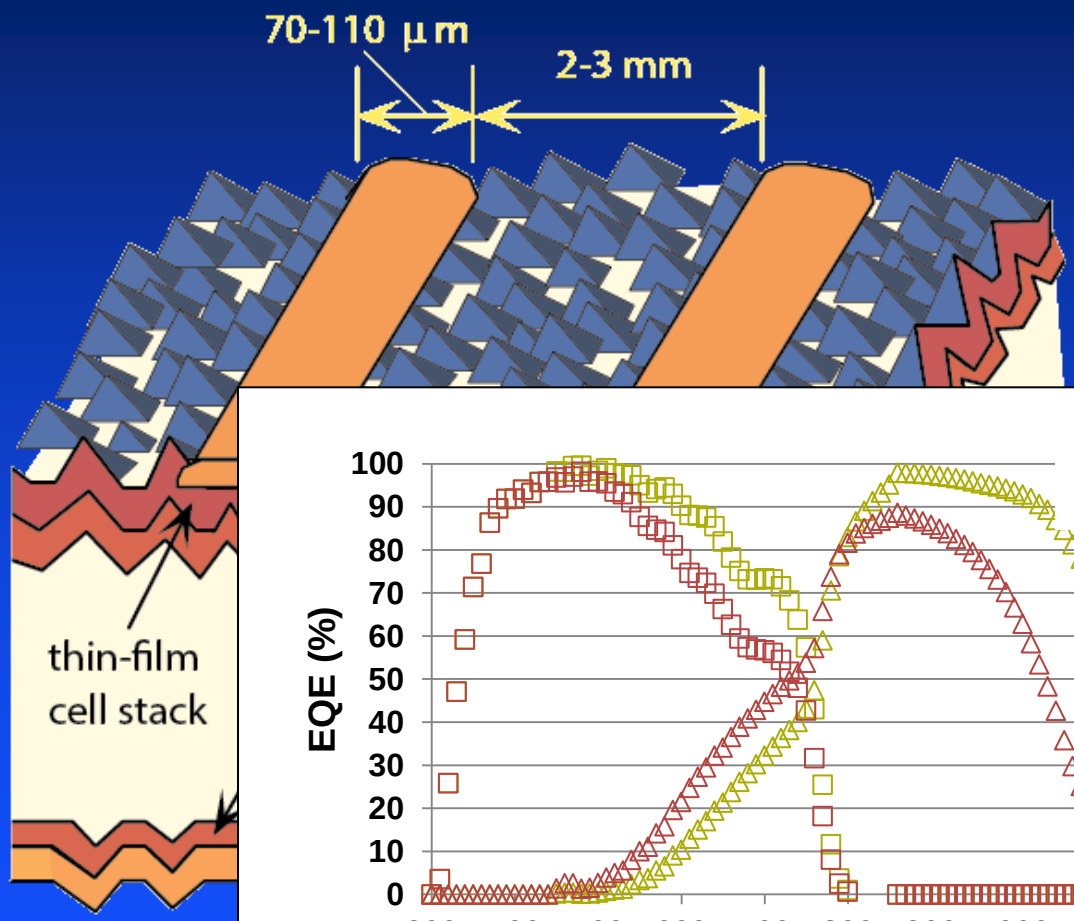
Free choice or Si



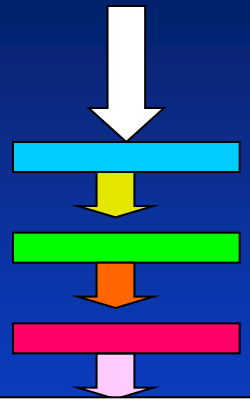
Perovskite on Si?

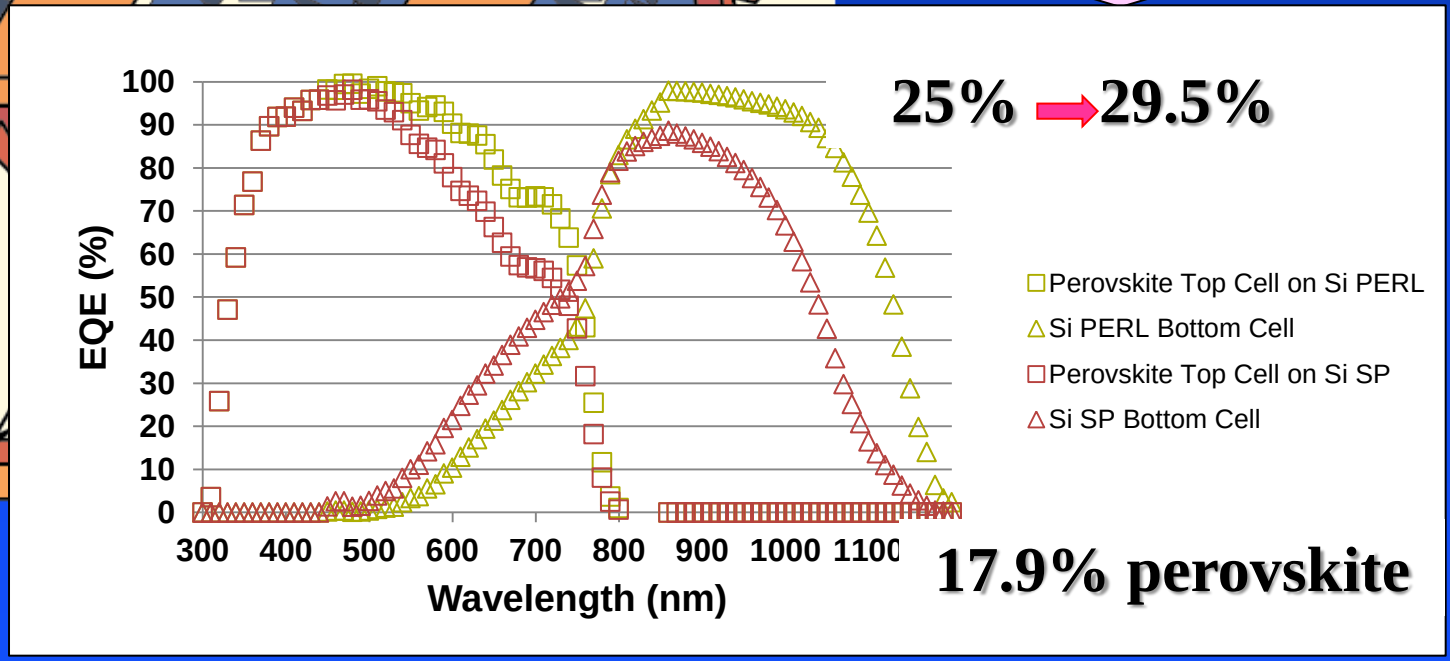


Perovskite on Si?



perovskite cell





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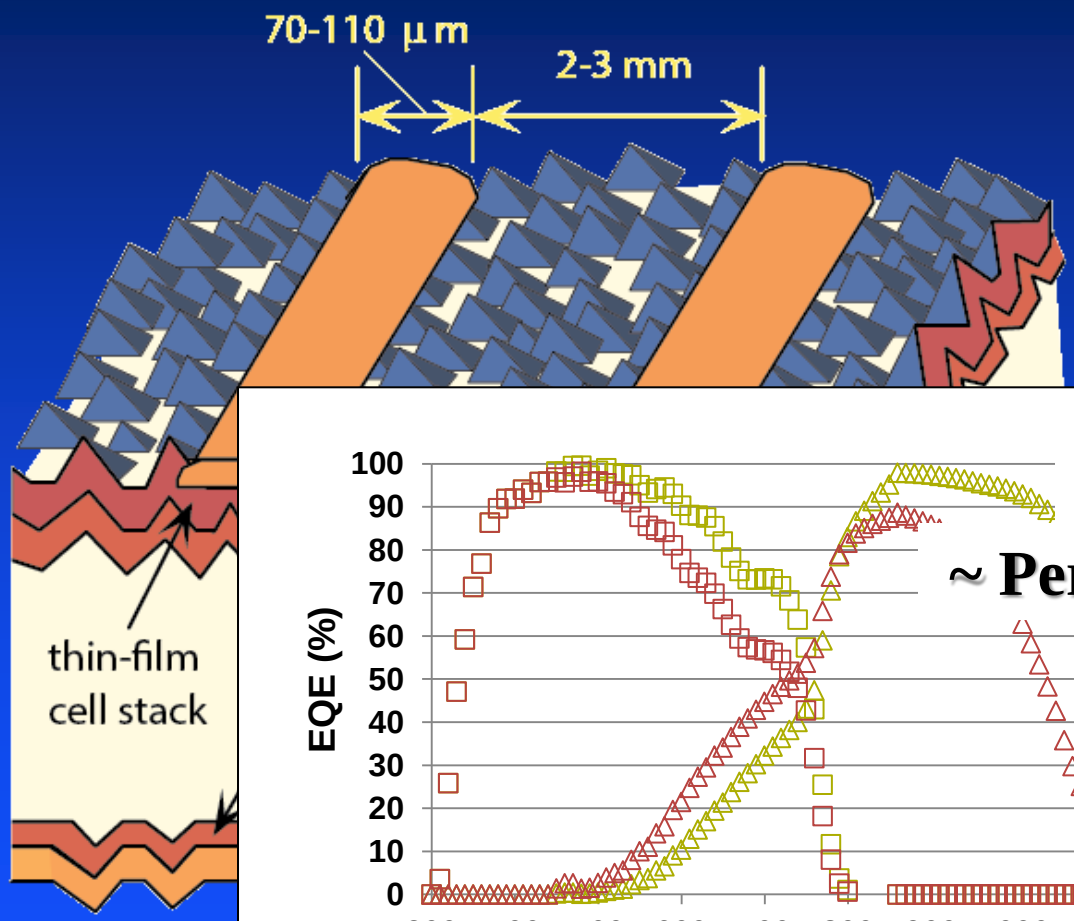
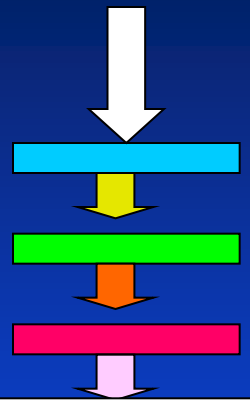
Perovskite on Si?



perovskite cell



25% → 29.5%

~ Perovskite% + Si%/2

17.9% perovskite

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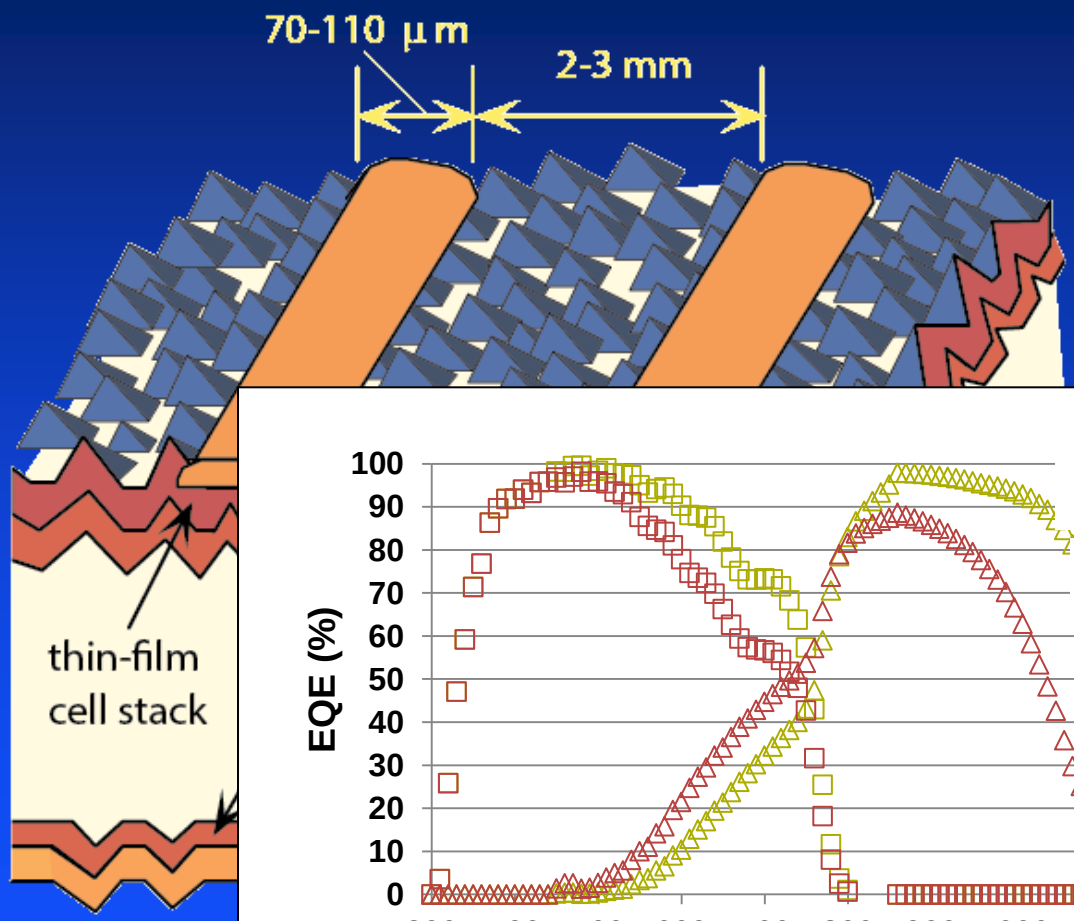
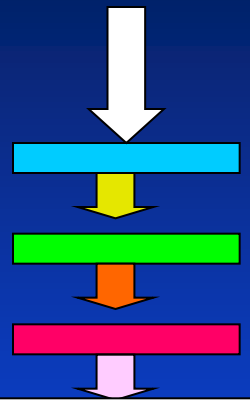
Perovskite on Si?



perovskite cell



25% → 29.5%

16.5% → 25%

17.9% perovskite

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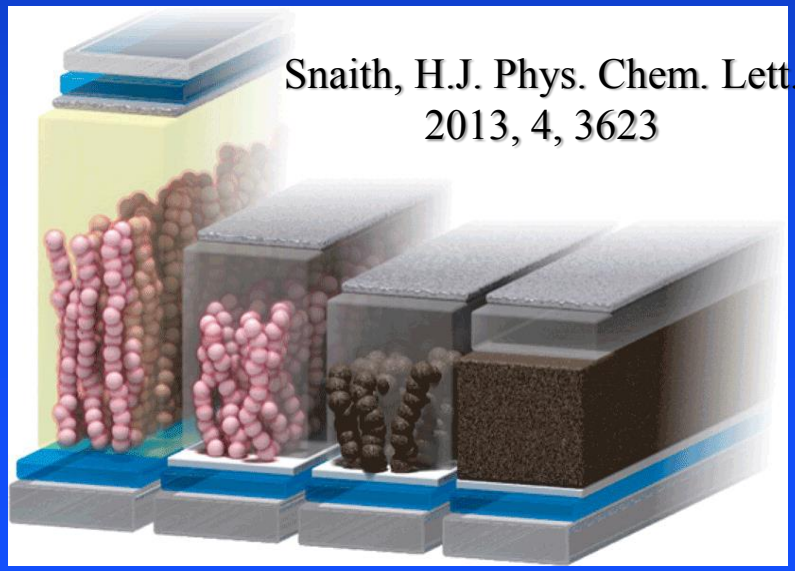
Summary

. *Exciting time for perovskites*



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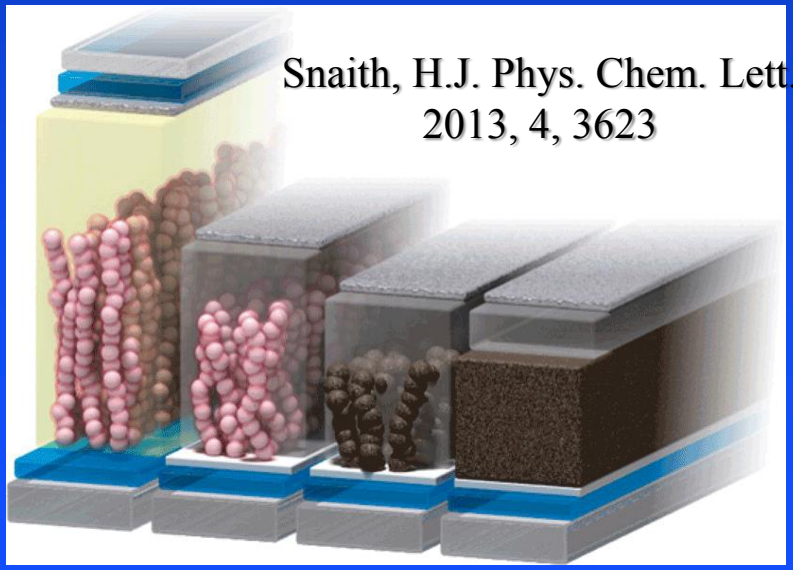
Summary

- *Exciting time for perovskites*
- *Competitive advantages?:*



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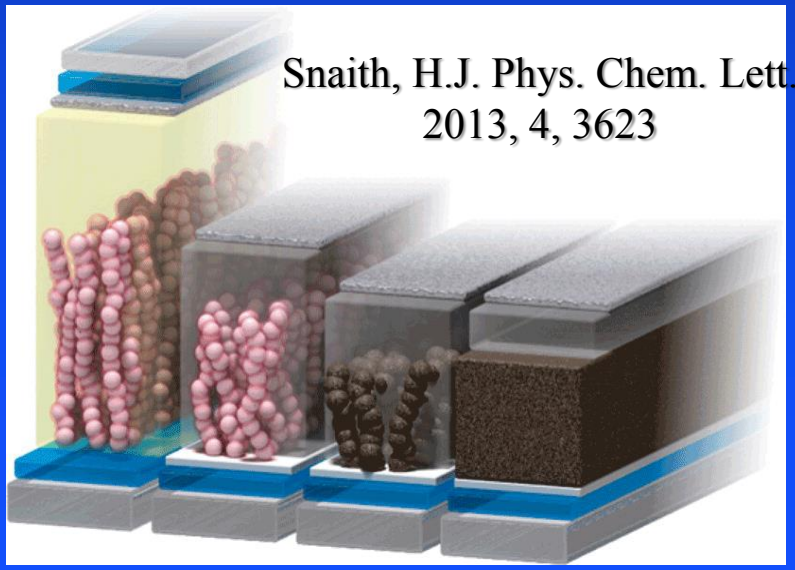
Summary

- Exciting time for perovskites
- Competitive advantages?:
  - Low cost fabrication?



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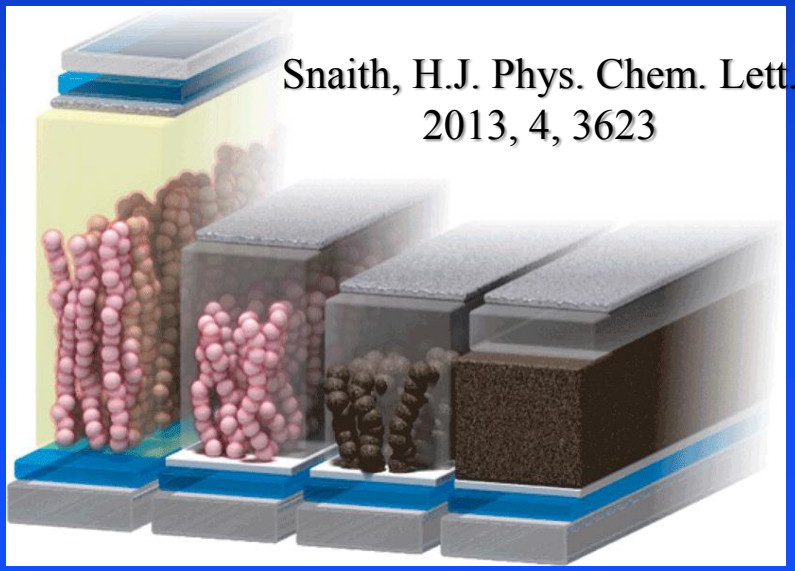
Summary

- Exciting time for perovskites
- Competitive advantages?:
  - Low cost fabrication?
  - Transparent and/or flexible product?



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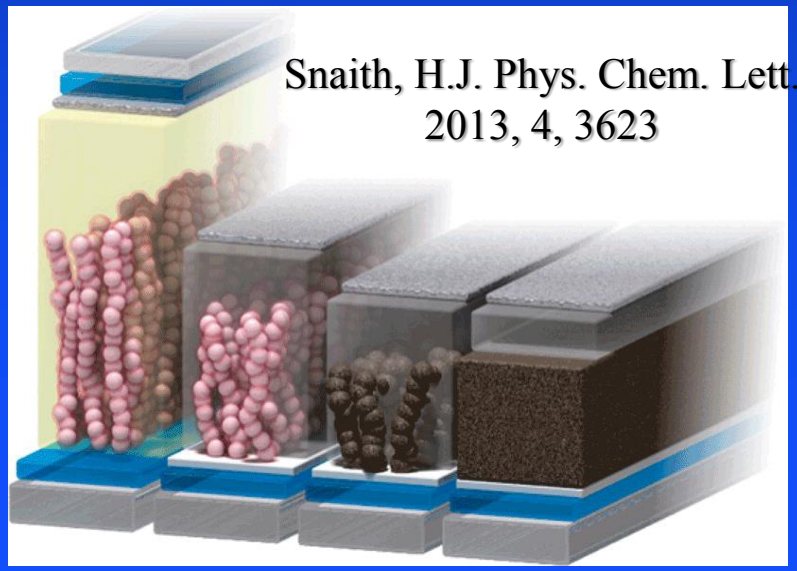
Summary

- Exciting time for perovskites
- Competitive advantages?:
  - Low cost fabrication?
  - Transparent and/or flexible product?
  - Ability to form tandems?



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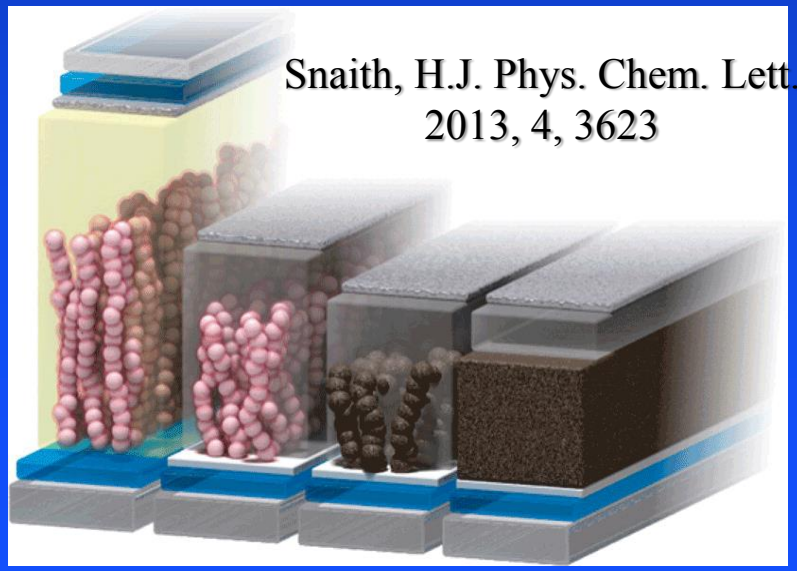
Summary

- Exciting time for perovskites
- Competitive advantages?:
  - Low cost fabrication?
  - Transparent and/or flexible product?
  - Ability to form tandems?
- Moisture sensitivity and toxicity of Pb



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