LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

NANO SPECTROSCOPY

Halide Perovskites for Solar Cells, LEDs, Lasers, and more….

Summer Semester 2020

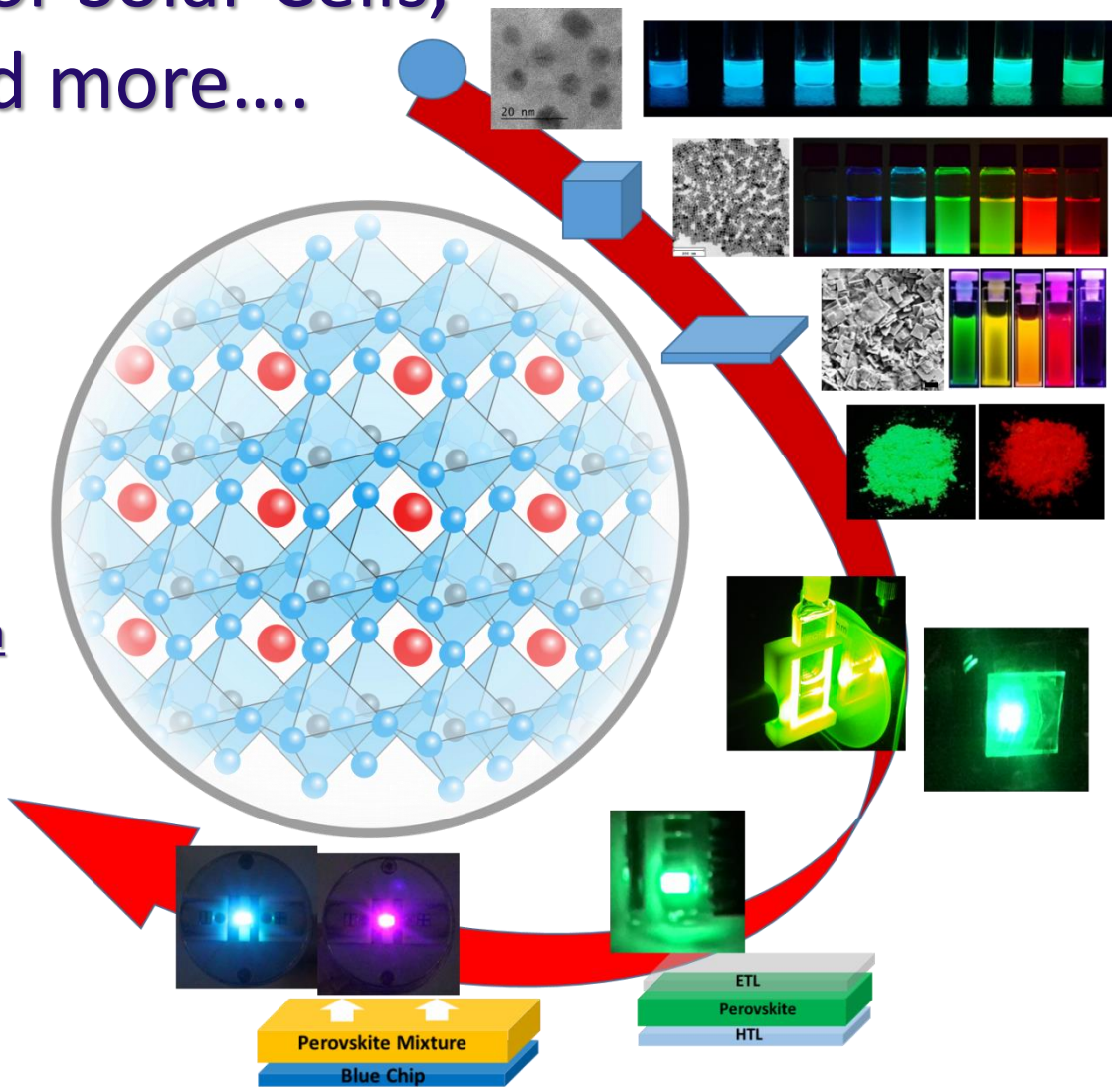
Tuesdays, 14:00-16:00 Uhr s.t.
- online via zoom -

First seminar: 21.04.2020
Last seminar: 21.07.2020

Prof. Dr.
Alexander Urban

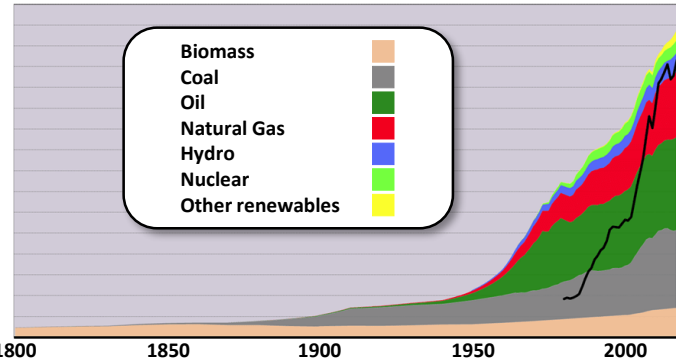
M.Sc.
Moritz Gramlich

Nanospectroscopy Group,
Department of Physics
Königinstr. 10, 80539 München

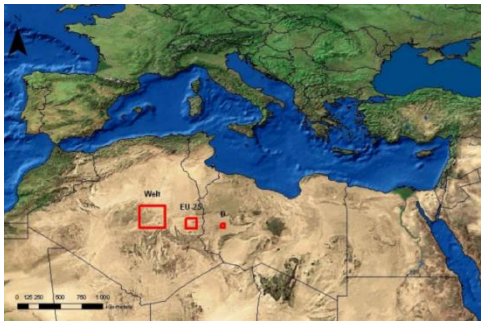


Importance of solar energy and efficient solar cells

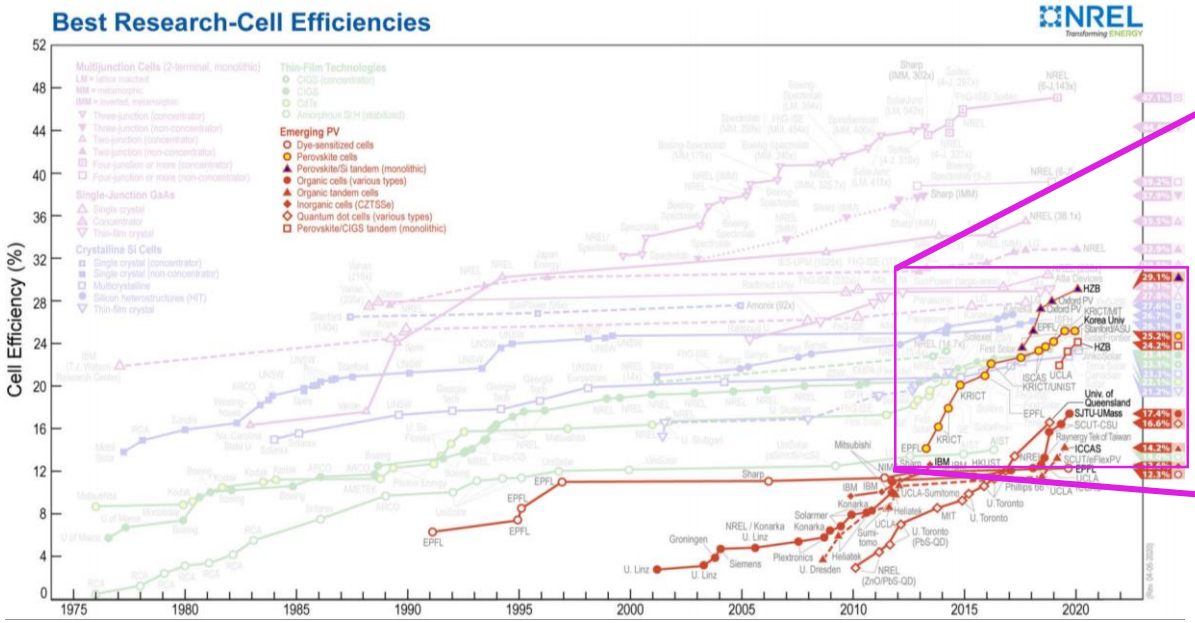
The world's power consumption is rapidly increasing…



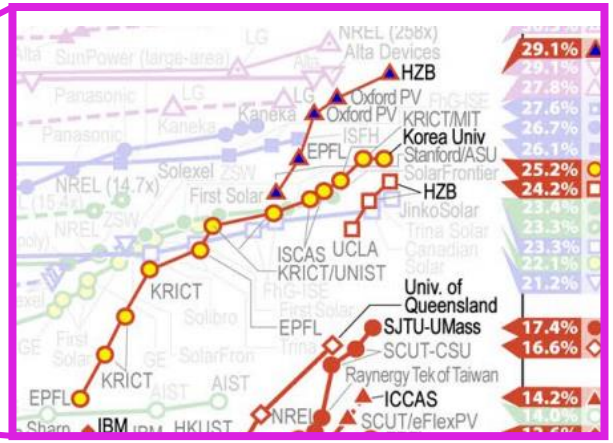
Solar energy enough to sustain demand…



While solar cell efficiencies slowly improve…



Perovskite solar-cells race forward…



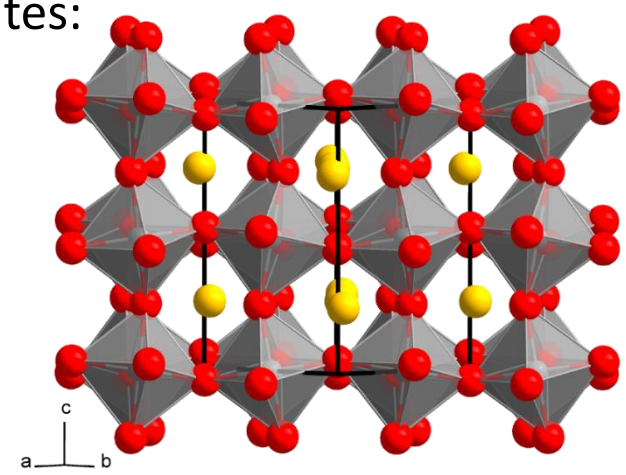
2009: 3.5 % efficiency
2019: 25.2 % efficiency

What is perovskite?

"Perovskite is **calcium titanate**, with the chemical formula $CaTiO_3$.

The mineral was discovered by Gustav Rose in 1839 and is named after the Russian mineralogist Count Lev Alekseevich Perovski (1792-1856)"

All materials with the same crystal structure as $CaTiO_3$, namely ABX_3, are termed perovskites:

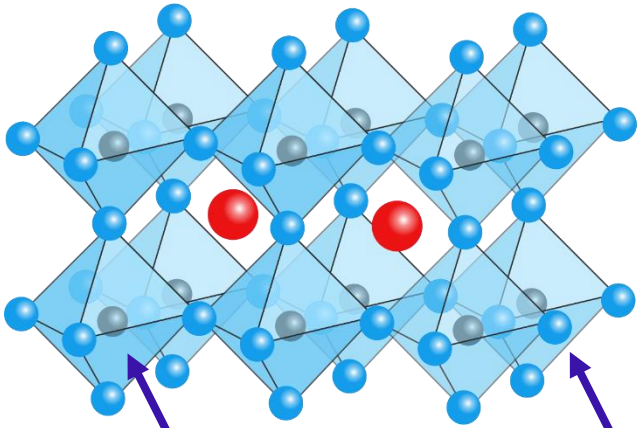


www.wikipedia.org

Hybrid halide perovskites: crystal structure

All-inorganic

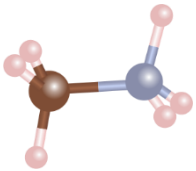
Cesium



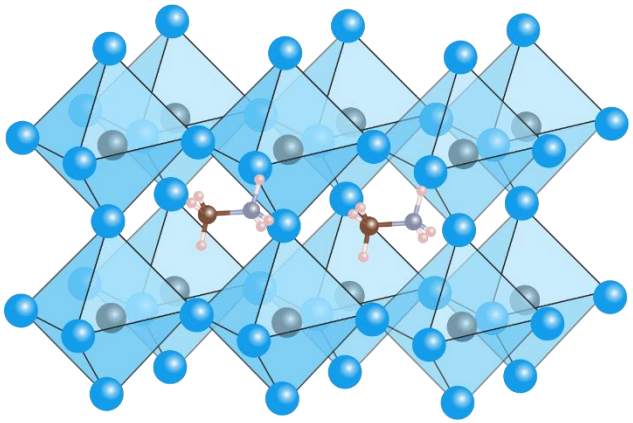
B : Pb^{2+}, Sn^{2+}, …

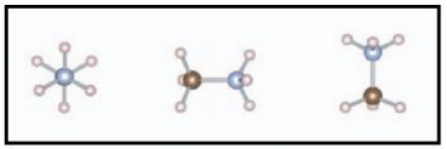
X : I^-, Br^-, Cl^-

Hybrid organic/inorganic



Methylammonium ($CH_3NH_3^+$)





Orientational Disorder

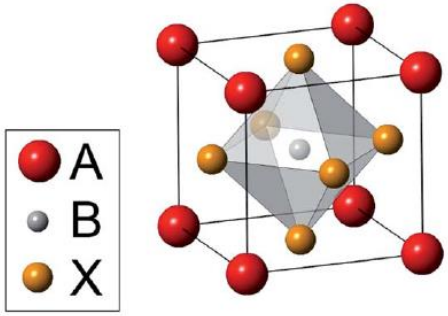
Perovskites: success story

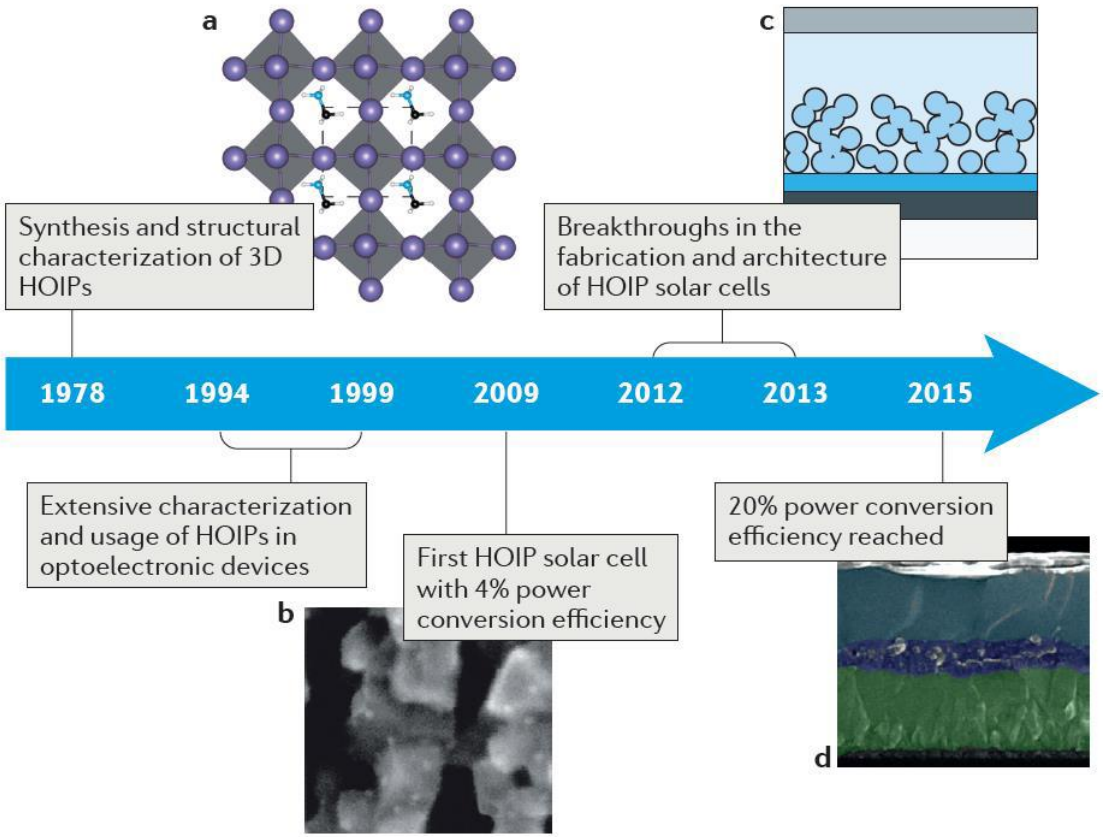
1839: Original perovskite: $CaTiO_3$

Count Lev Aleksevich von Perovski

Perovskite describes a crystal structure class: generally ABO_3

Halide perovskites:





Chemical structure: ABX_3

A: organic/inorganic cation (methylamine, formamidium, cesium)

B: metal cation (Pb, Sn, …)

X: halide anion (Cl, Br, I)

5

Halide perovskites: Excellent photovoltaics

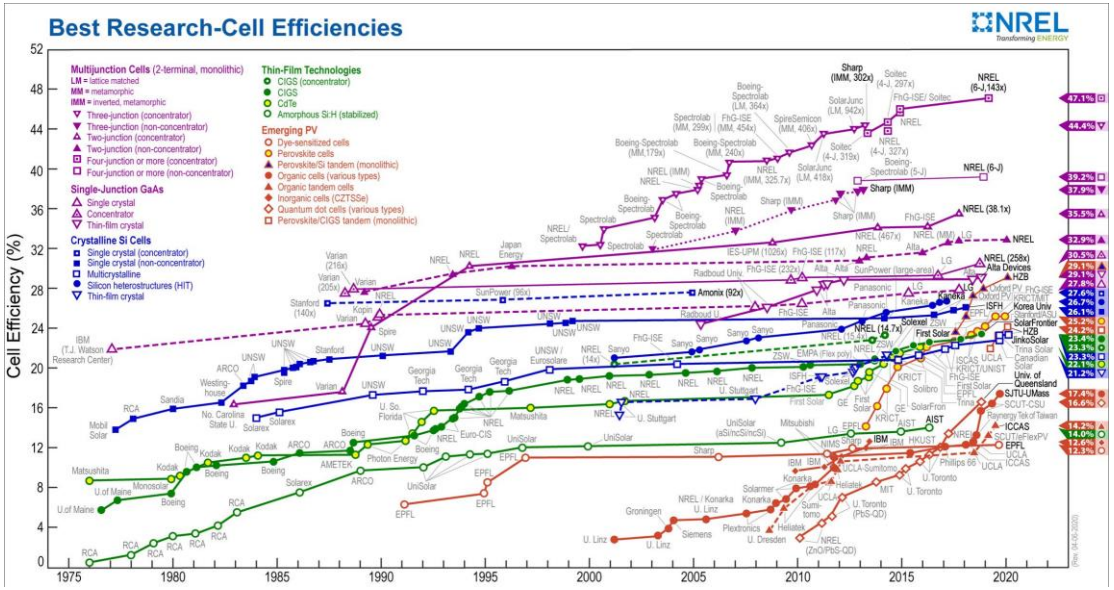
Oct 28th 2013

The Economist

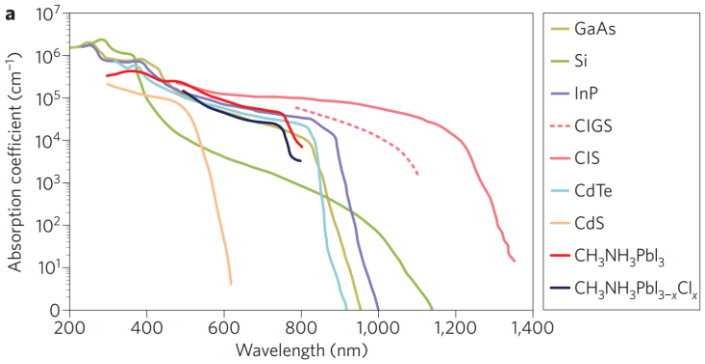
Solar energy

Cell a million?

A new material may cut the cost of generating solar electricity by three-quarters

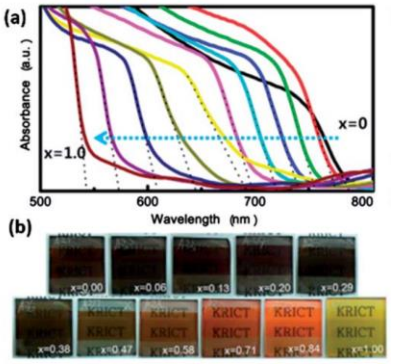


Very high absorption -> thin active layers
(~ 300 nm, compared to Si: 100-200µm)



P. Gao, M. Grätzel, M. K. Nazeeruddin. En. Env. Sci. 7 (2014): 2448-2463.

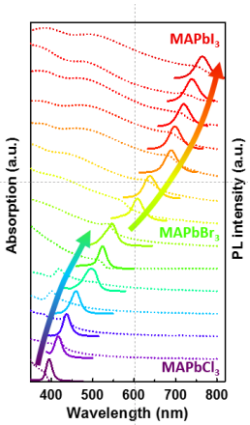
Bandgap tunable through halide composition



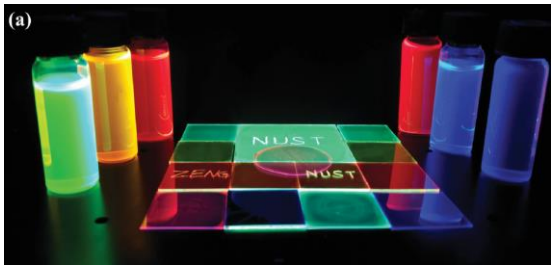
M. A. Green, A. Ho-Baillie, H. J. Snaith. Nat. Photon. 8 (2014): 506-514.

Halide perovskites for light emission

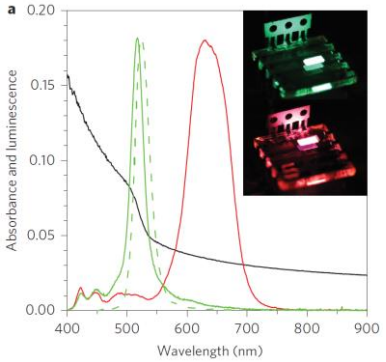
Not only for light conversion, also light emission!



V. Hintermayr, Urban, AS, et al. *Adv. Mater.*, 26, 2435 (**2016**)



Li, X. et al., *Adv. Func. Mater.*, 26, 2435 (**2016**)



Tan, Z.K. et al., *Nat. Nanotech.* 9, 687 (**2014**)

However, PL quantum efficiency in films: 20-50%

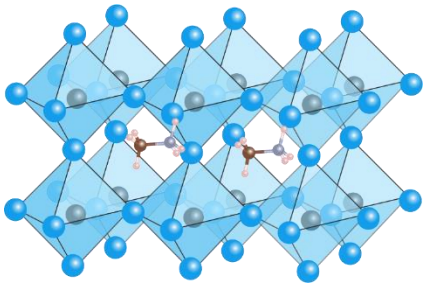
Semiconductor nanocrystals: Emission tunable through size

Source: Prof. Andrey Rogach, City University of Hong Kong

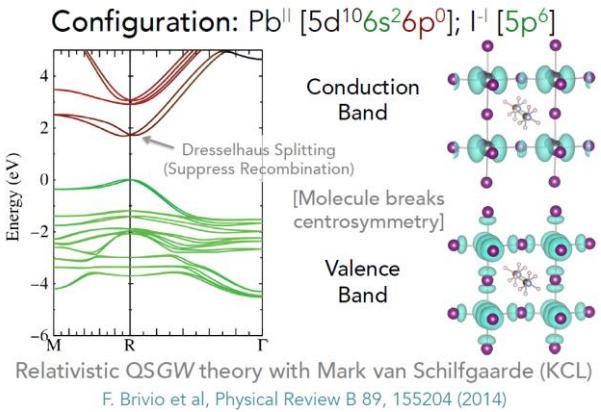
-> Perovskite nanocrystals

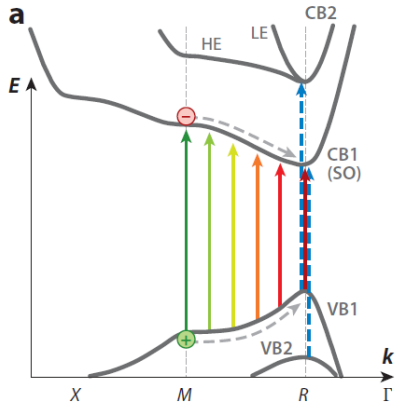
Topics: Fundamentals

Crystal structure / composition

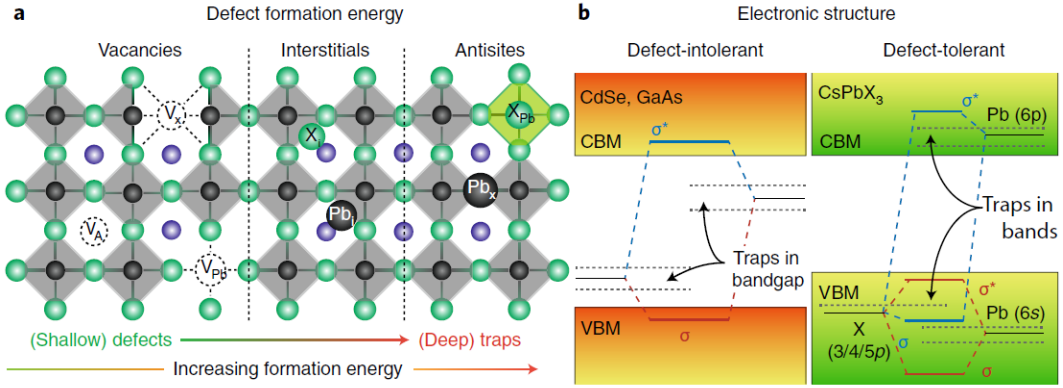


Optical / energetic properties

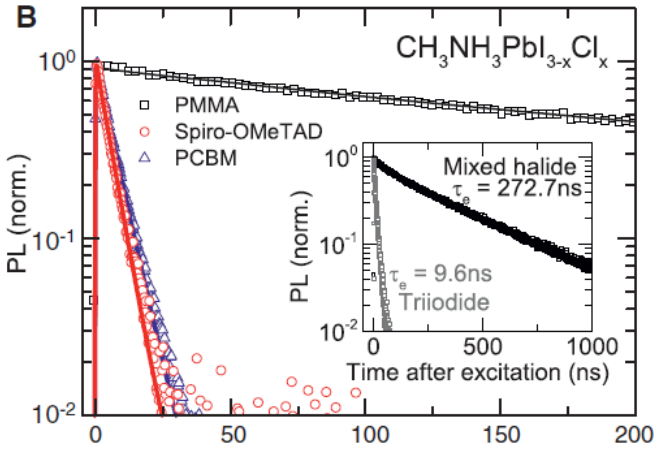




Trap states / defect tolerance

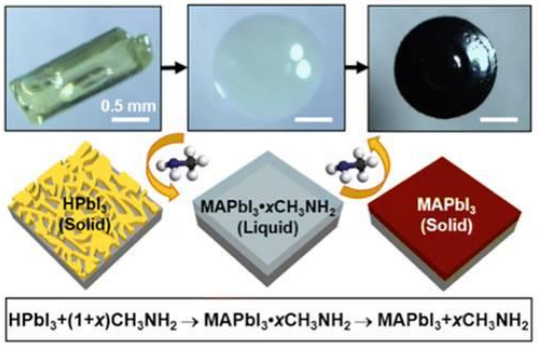


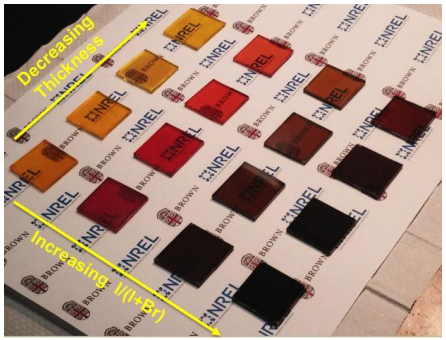
Carrier lifetimes / transport (mobility)



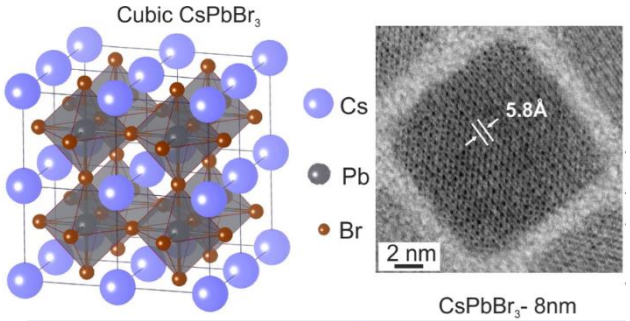
Topics: Materials

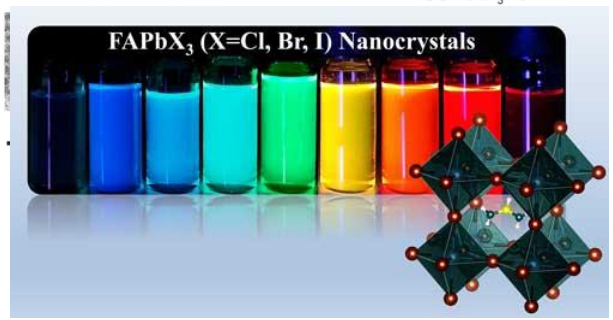
Perovskite (bulk) films



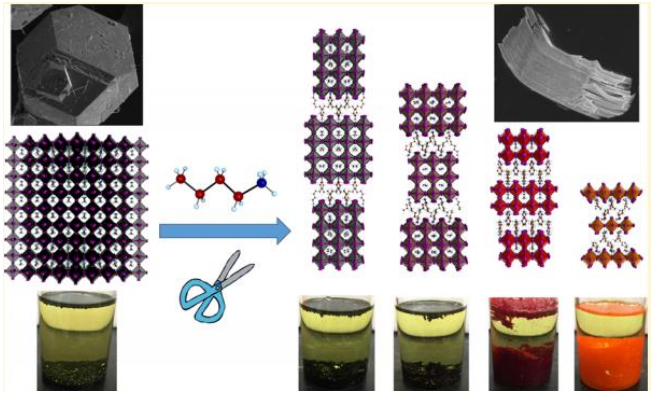


Nanocrystals (0D -1D -2D -3D)



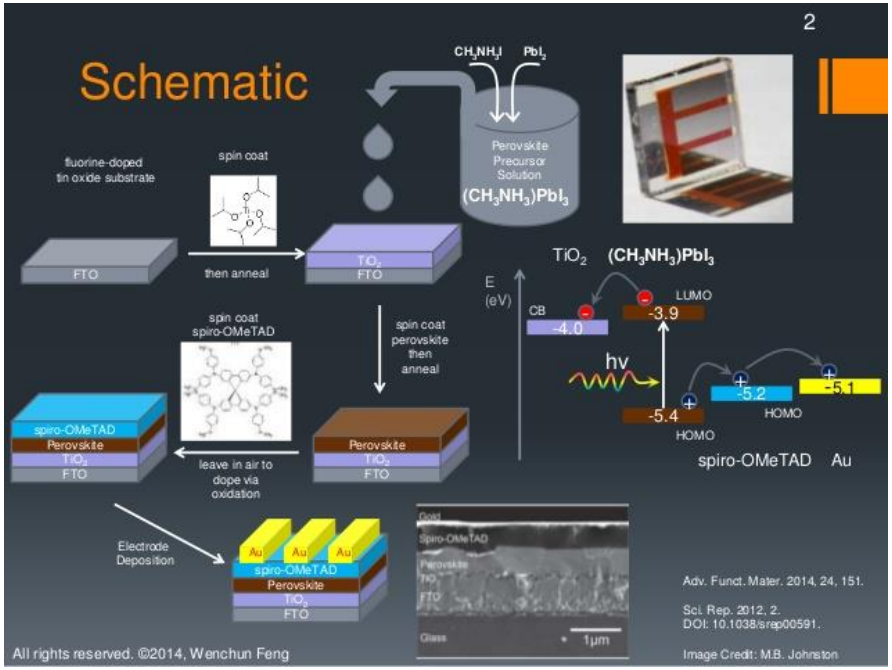


2D Layered Perovskites (Ruddlesden-Popper)

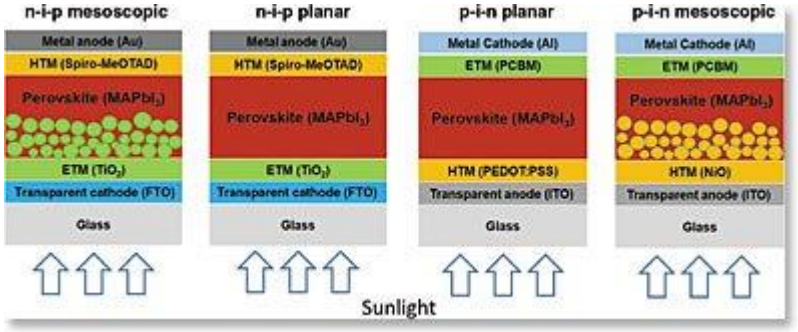


Topics: Devices – Solar Cells

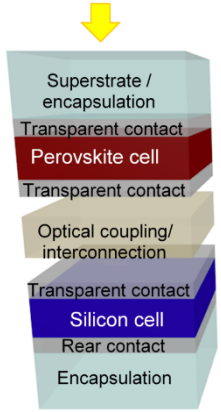
Fabrication

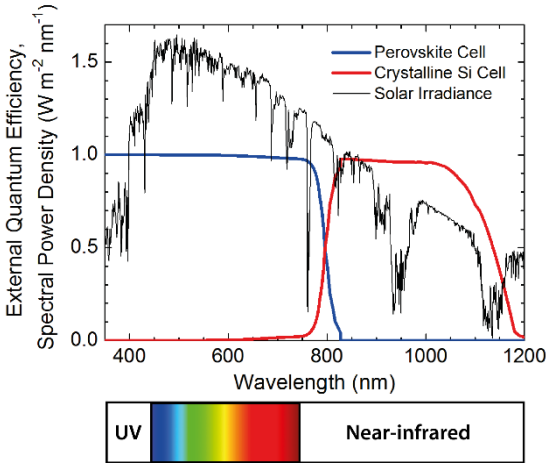


Architechtures / working principles

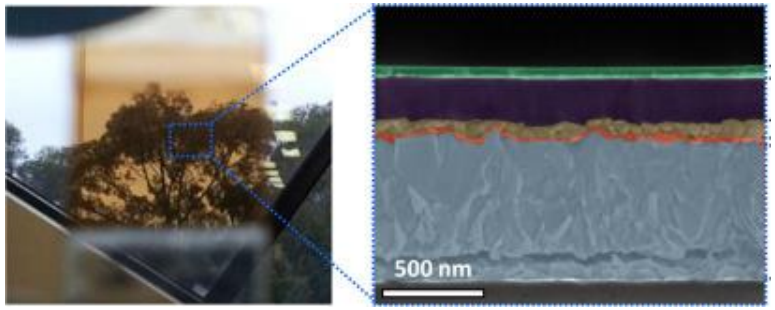


Multi-junction / tandem solar cells



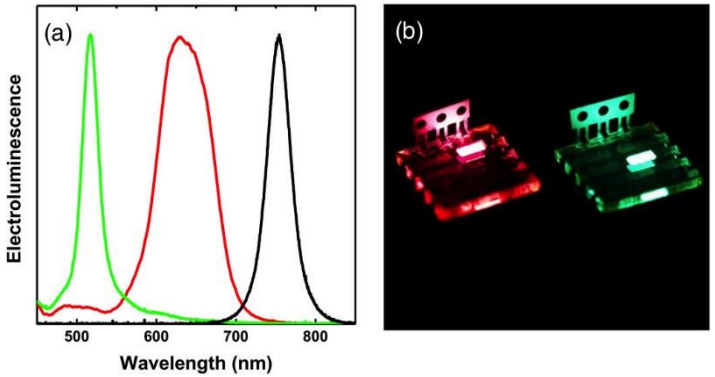


Semi-transparent solar cells

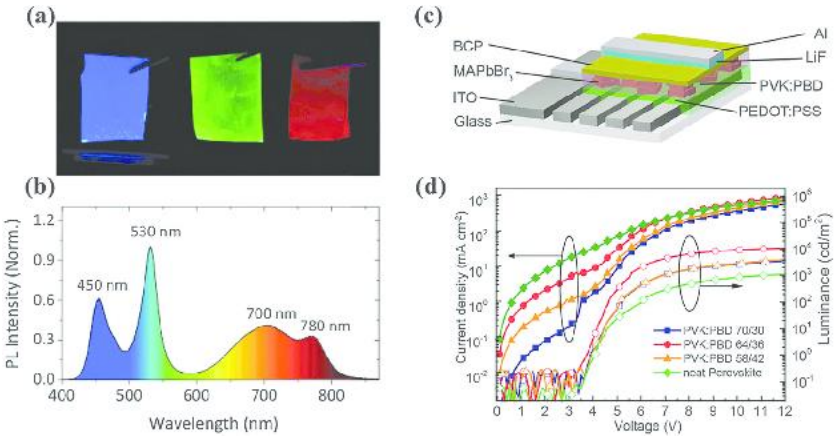


Topics: Devices – LEDs

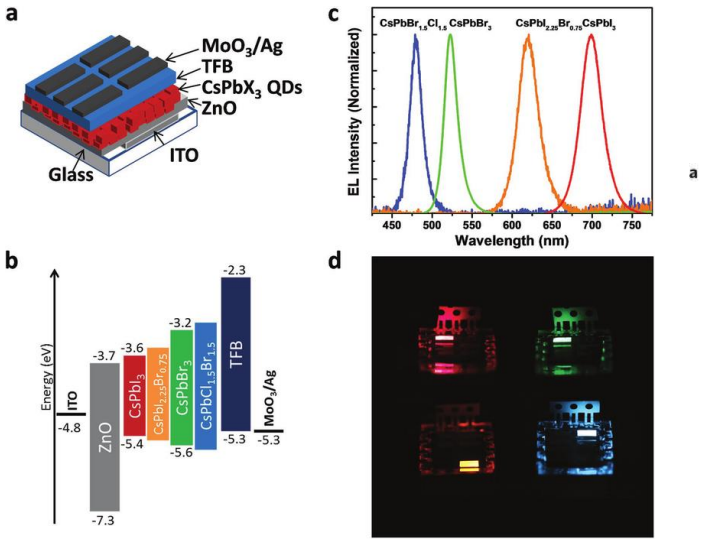
Perovskite LEDs (films)



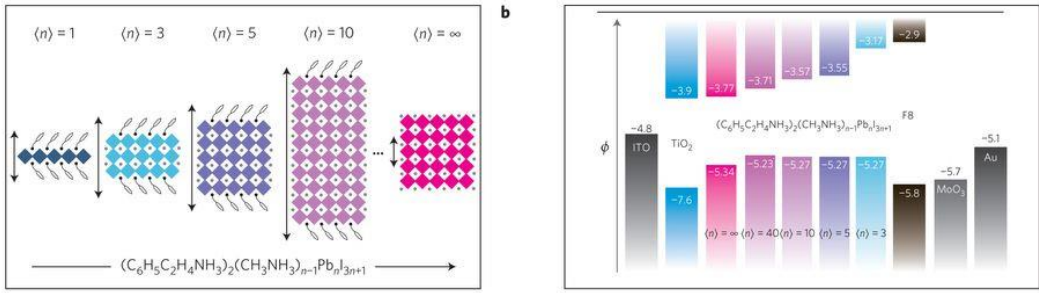
White-light emitting LEDs



Nanocrystal-based LEDs

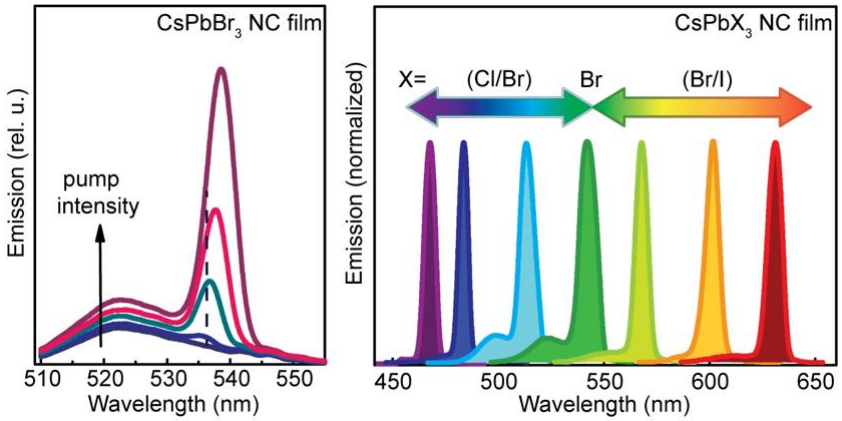


Cascaded Energy Transfer (Energy Funnels)

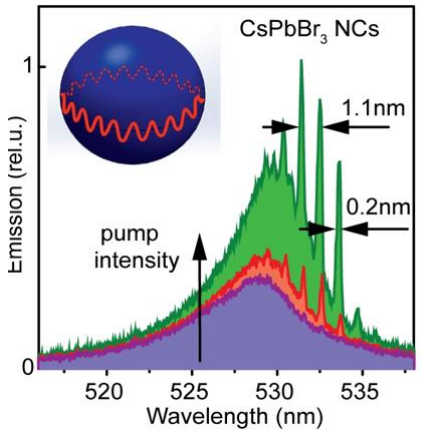


Topics: Devices – Lasers

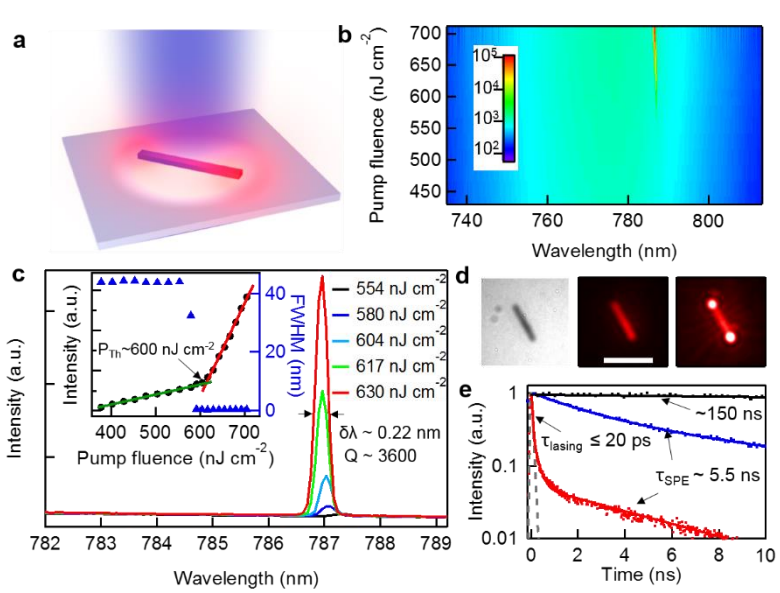
Amplified spontaneous emission (ASE)



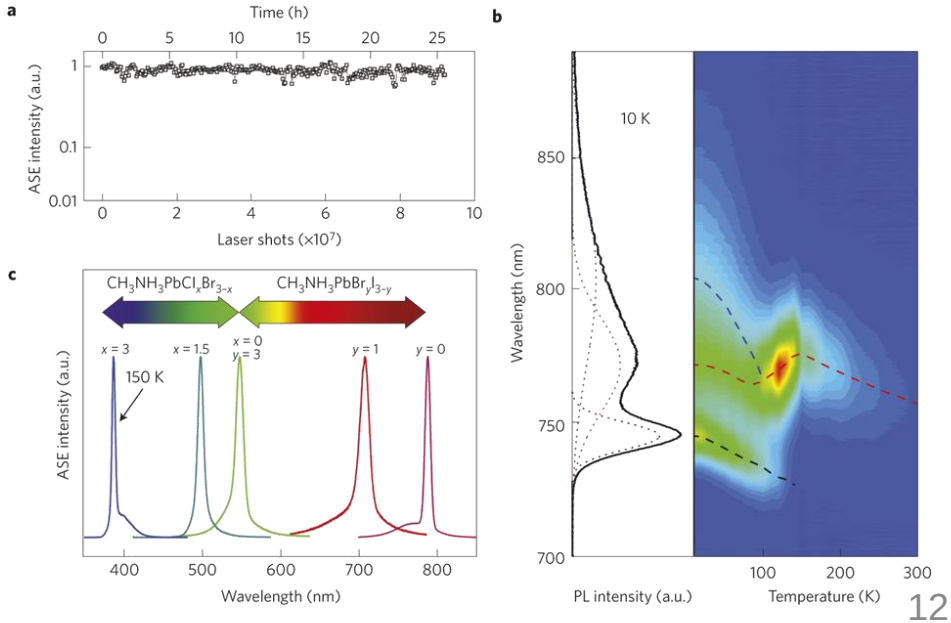
Random lasing



Nanocrystal lasing

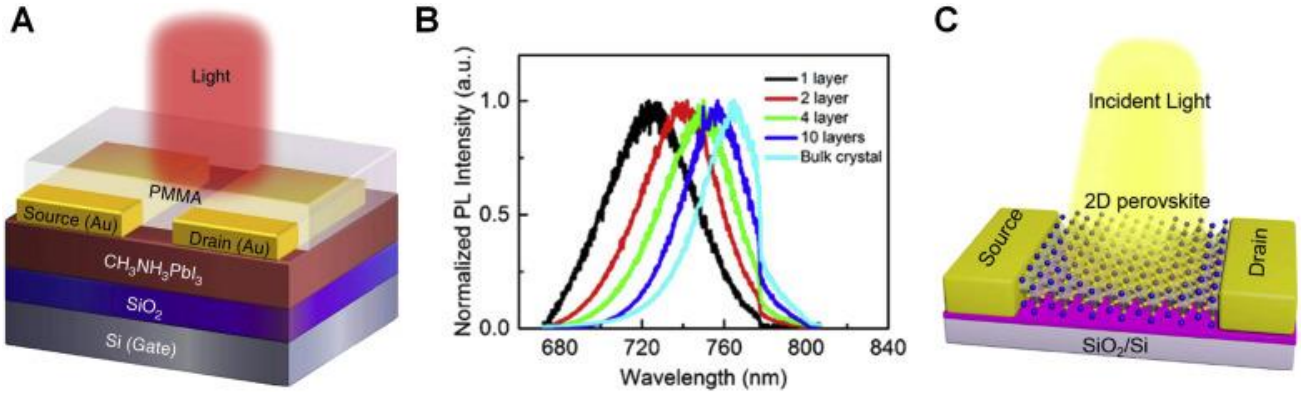


Cavity lasing

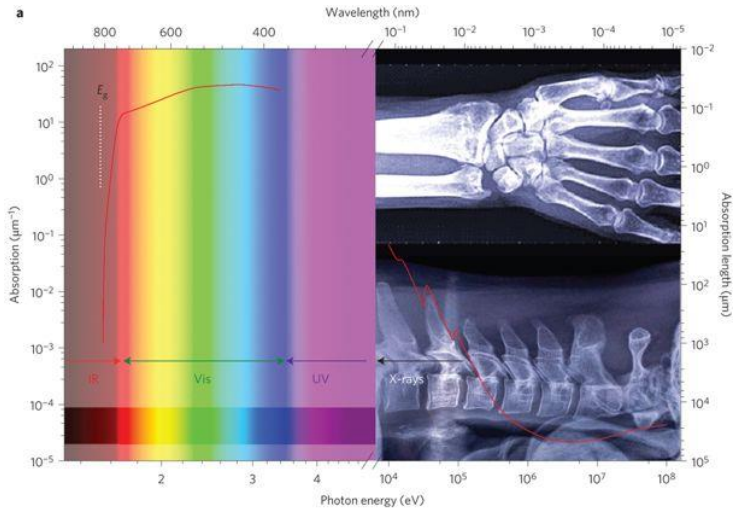


Topics: Devices – Detectors

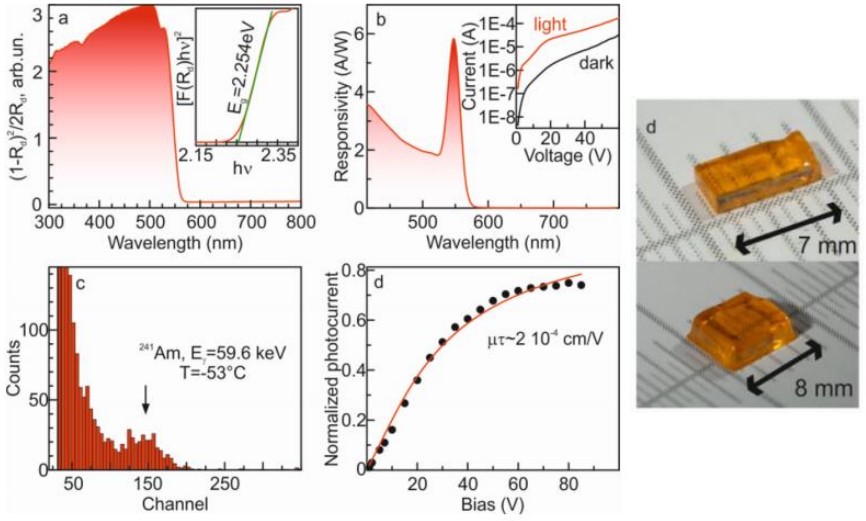
Photodetectors



X-ray detector

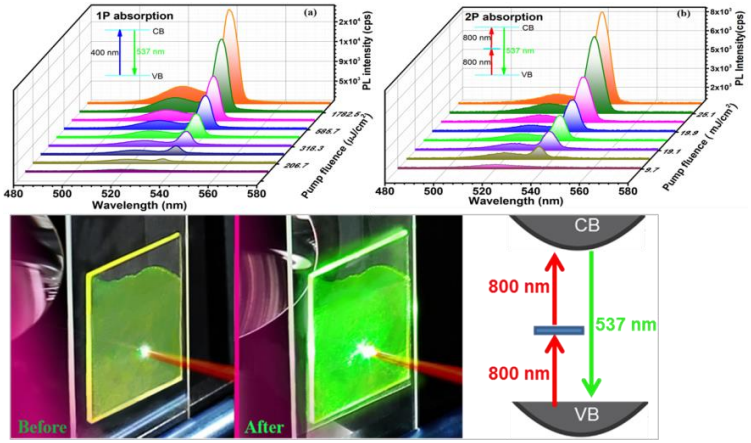


Gamma-ray detector

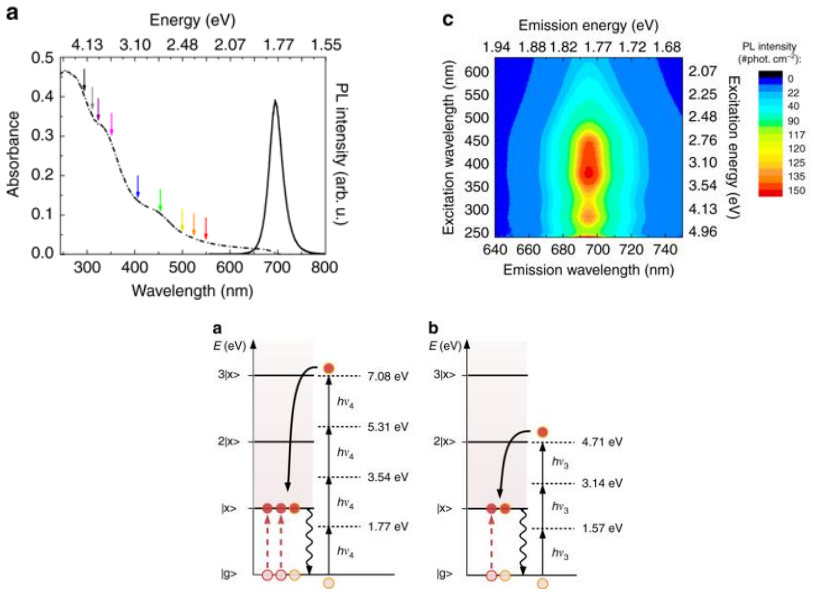


Topics: Physics of Perovskites

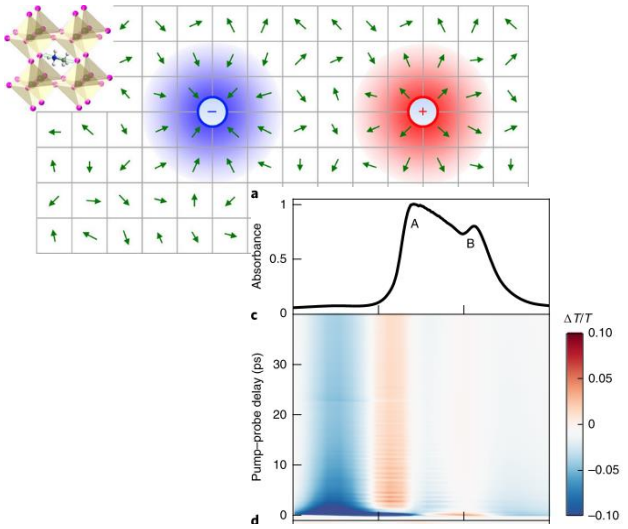
Multiphoton excitation



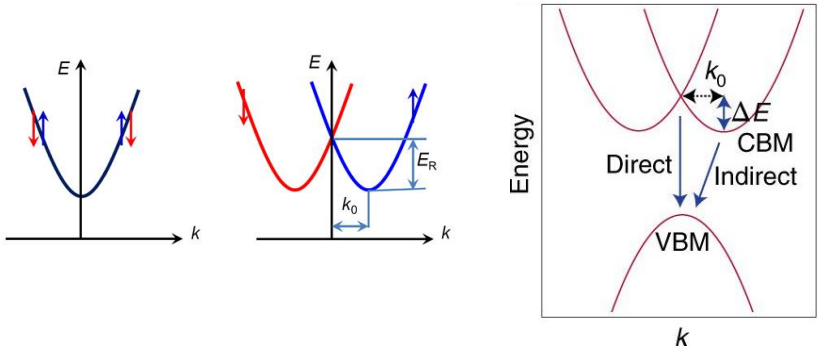
Carrier Multiplication



Polaron formation

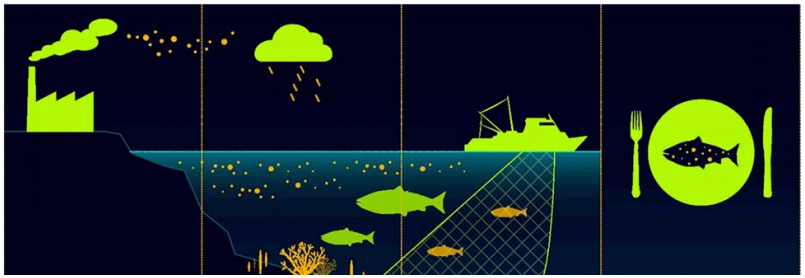


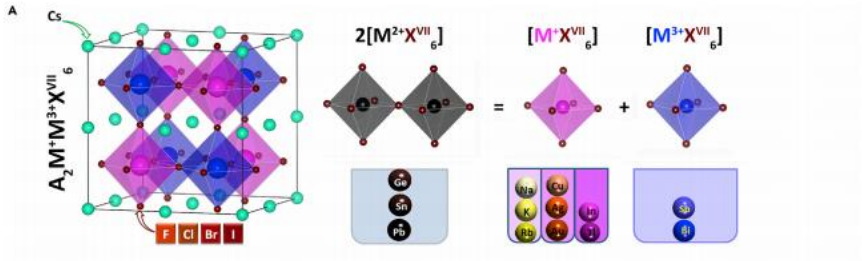
Rashba effect



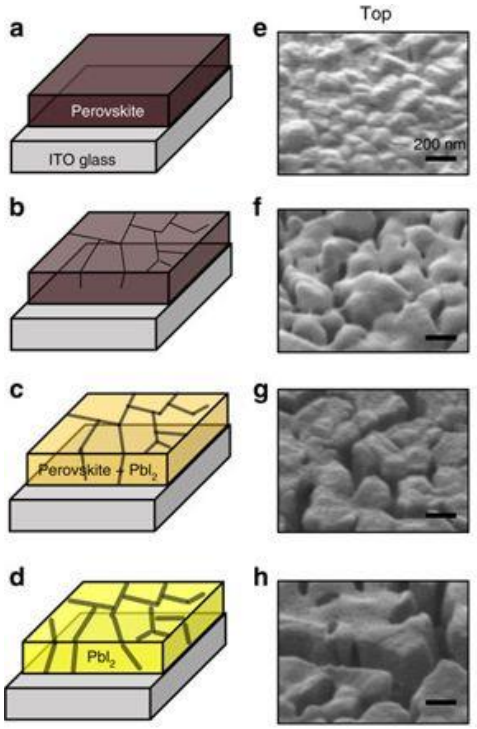
Topics: Problems in Perovskite

Toxicity: Lead

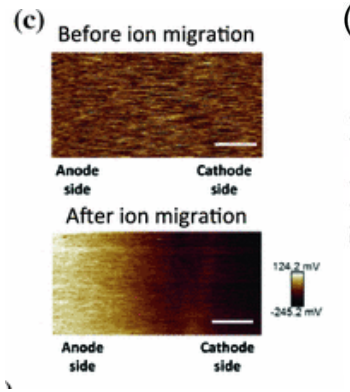


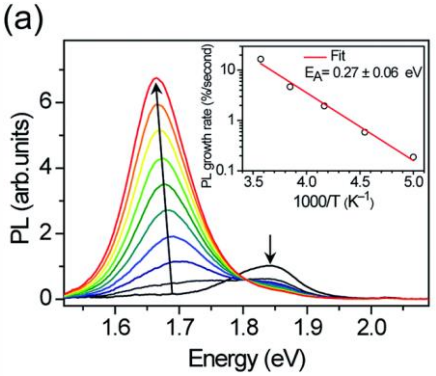


Stability



(Halide) Ion Migration





Seminar: Goals, structure, schedule

- Two topics (talks) per week
- Everyone must prepare a topic and give a talk
- Initial material provided
- Goals:
  - Become acquainted with a new topic
  - Read, understand and present reseach articles
  - Search for additional material (background materials, additional articles)
  - Prepare a presentation
  - Give a talk (approx. 30 minutes)
  - Answer questions on topic (15 minutes)
- Talk: 30 minutes -> roughly 20 slides
- Start with introduction to topic
- Include figures, highlighting studies, findings
- Include the citations to all material copied from journal articles
- Everyone not giving a talk is expected to ask questions and participate in the discussions.
- Weekly attendance is mandatory.

Schedule

week	date		Topics	Speaker
1	21.04	Introduction		A. Urban
2	28.04	seminar 0	Perovskite Basics	Moritz Gramlich
3	05.05	seminar 1		
4	12.05	seminar 2		
5	19.05	seminar 3		
6	26.05	seminar 4		
7	02.06	seminar 5		
8	09.06	seminar 6		
9	16.06	seminar 7		as needed
10	23.06	seminar 8		as needed
11	30.06	seminar 9		as needed
12	07.07	seminar 10		as needed
13	14.07	seminar 11		as needed
14	21.07	seminar 12		as needed

Schedule

Schedule

week	date		Topics	Speaker
1	21.04	Introduction		A. Urban
2	28.04	seminar 0	Perovskite Basics	Moritz Gramlich
3	05.05	seminar 1		
4	12.05	seminar 2		
5	19.05	seminar 3		
6	26.05	seminar 4		
7	02.06	seminar 5		
8	09.06	seminar 6		
9	16.06	seminar 7		as needed
10	23.06	seminar 8		as needed
11	30.06	seminar 9		as needed
12	07.07	seminar 10		as needed
13	14.07	seminar 11		as needed
14	21.07	seminar 12		as needed

- **Fundamentals**
  - Basics of Halide Perovskites
  - Optical /Energetic Properties
  - Trap states / defect tolerance
  - Carrier recombination/relaxation
  - Charge carrier conduction (mobility)
- **Materials**
  - Films (synthesis, properties)
  - 2D Perovskites (Ruddlesden Popper)
  - Nanocrystals (0D, 1D, 2D, 3D)
- **Physics**
  - Multiphoton Excitation
  - Carrier Multiplication
  - Polaron formation
  - Rashba effect
- **Problems**
  - Toxicity: Lead
  - Stability
  - Halide Ion migration
- **Devices**
  - Solar Cells
    - Fabrication
    - Architectures / Working Principles
    - Multi-junction / Tandem Solar cells
    - Semi-transparent solar cells
  - LEDs
    - Film-based LEDs
    - Nanocrystal-based LEDs
    - White-light emittision
    - Cascaded Energy transfer (Funnels)
  - Lasers
    - Amplified Spontaneous emission (ASE)
    - Cavity lasing
    - Random lasing
    - Nanocrystal lasing
  - Detectors
    - Photodetectors
    - X-ray detectors
    - Gamma-ray detectors

Halide Perovskites for Solar Cells, LEDs, Lasers and more

Alexander Urban

Tel.: 089 2180-2039
Email: urban@lmu.de

Moritz Gramlich

Tel.: 089 2180-3444
Email: m.gramlich@physik.uni-muenchen.de

Nanospectroscopy Group,
Department of Physics
Königinstr. 10, 80539 München