Perovskite solar cells

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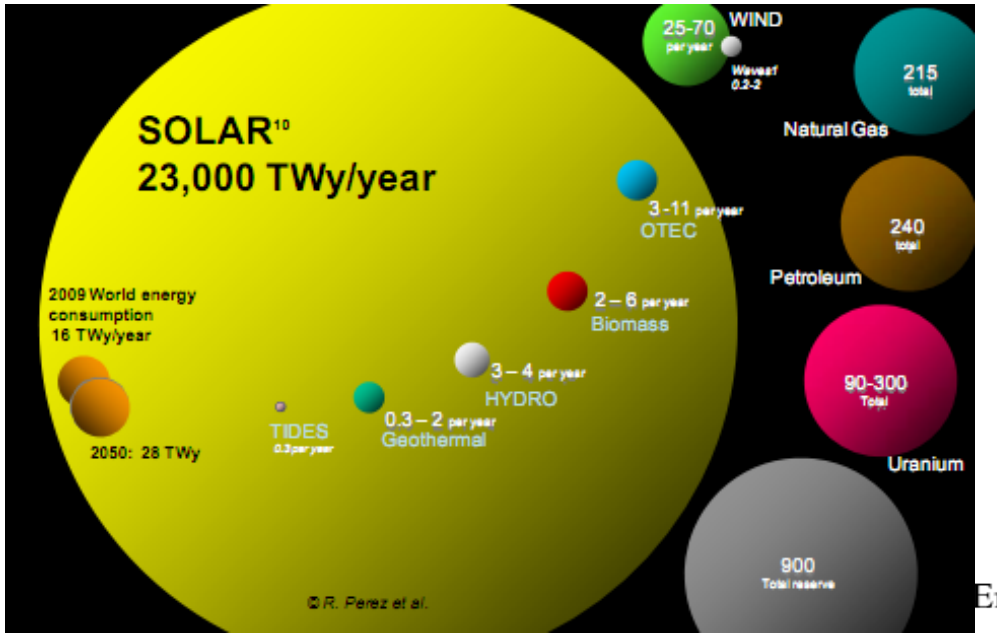
Outline

- Introduction: PV technologies
  - Silicon
  - Thin films
  - Multijunctions
  - Emerging PVs
- Perovskite solar cells
- VFP research projects

Solar Energy Facts

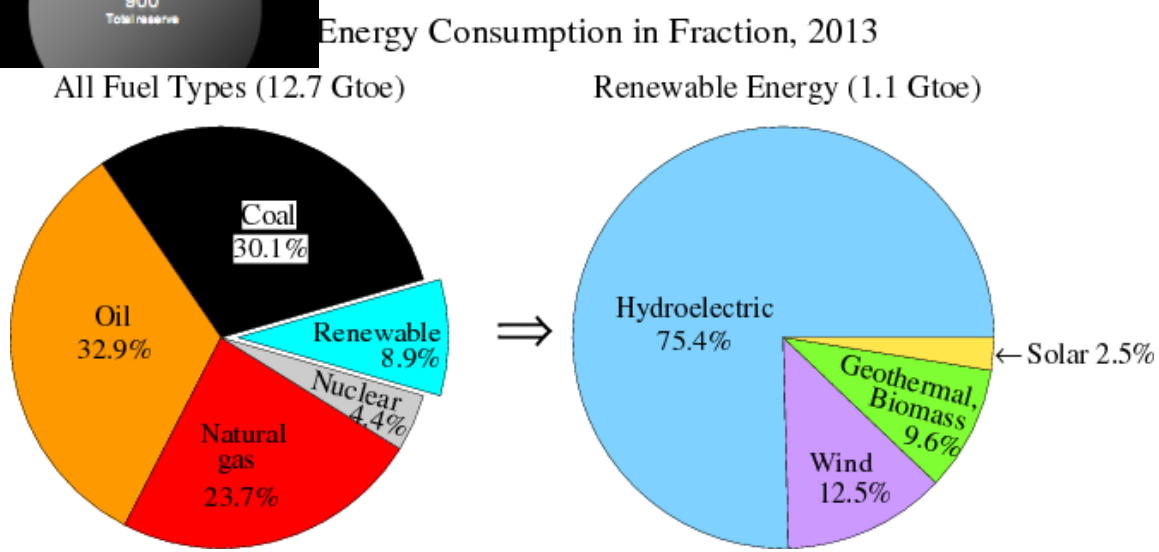


Solar Thermal:

Light ⟶ Heat

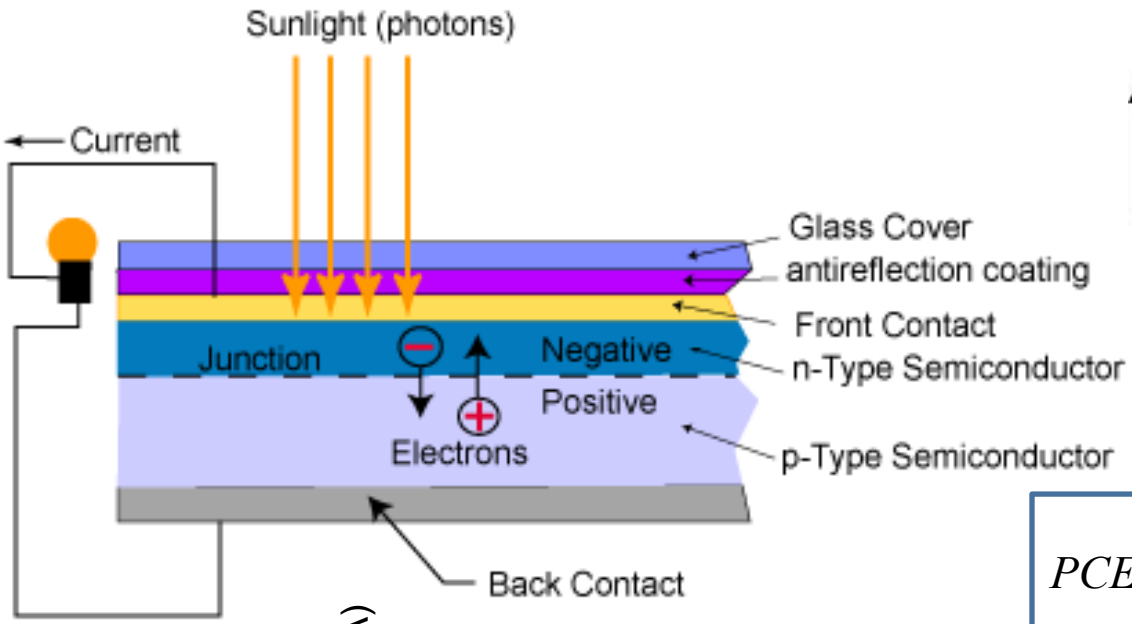
Solar photovoltaic (PV):

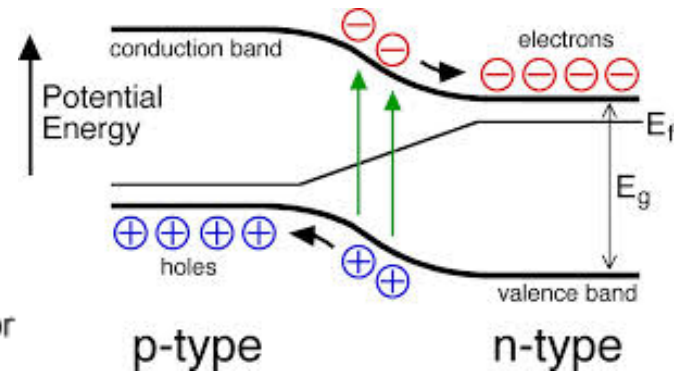
Light ⟶ Electricity



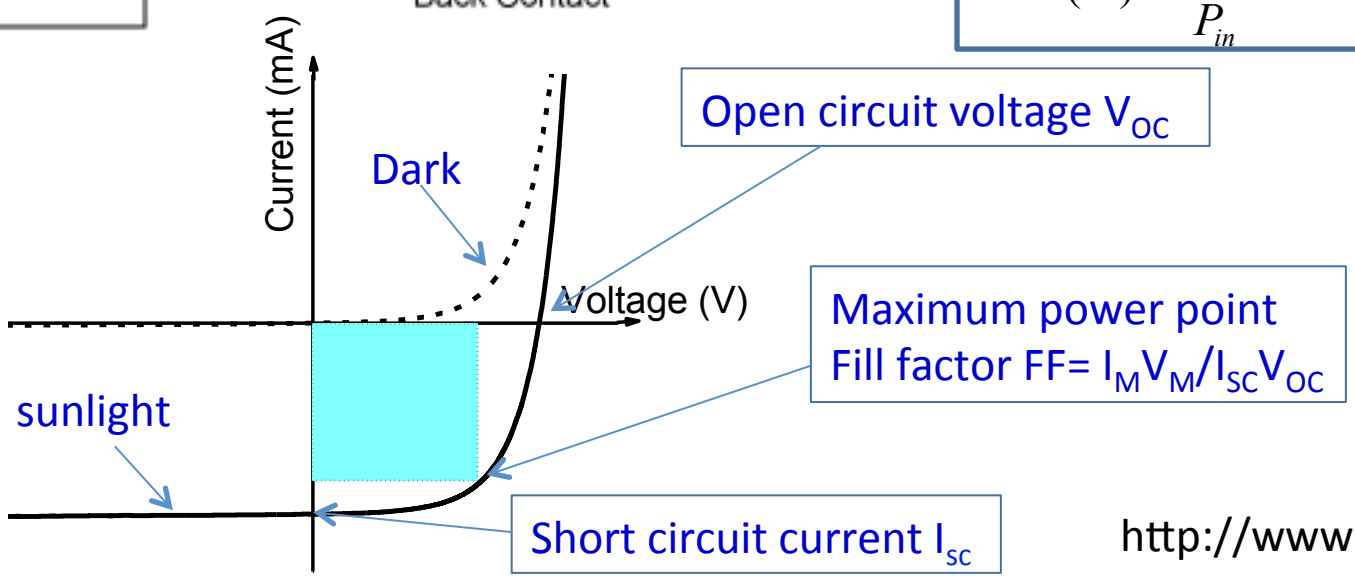
http://www.columbia.edu/~mhs119/EnergyConsump/

How photovoltaic solar cells work?





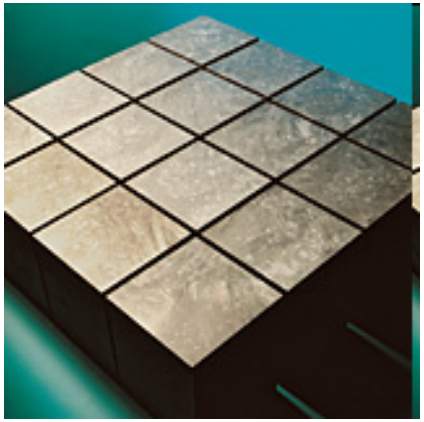
$$PCE(\%) = \frac{P_{out}}{P_{in}} = \frac{I_{SC} \bullet V_{OC} \bullet FF}{P_{in}} \times 100\%$$



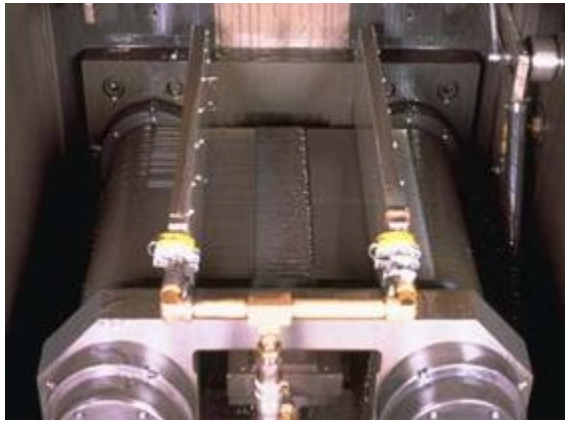
http://www.mysolarprojects.com

Crystalline Silicon PV

Silicon Feedstock

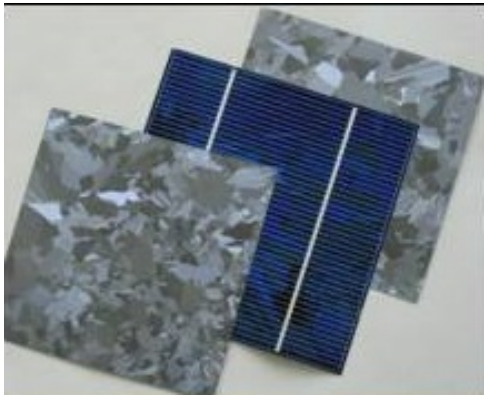


Ingot Growth



Slicing Wafers

Cell Fabrication

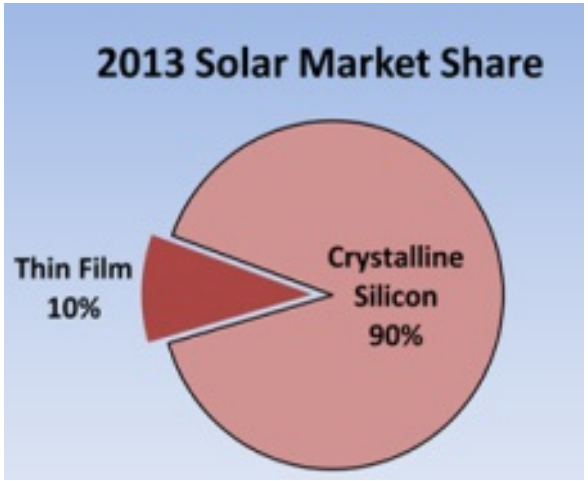


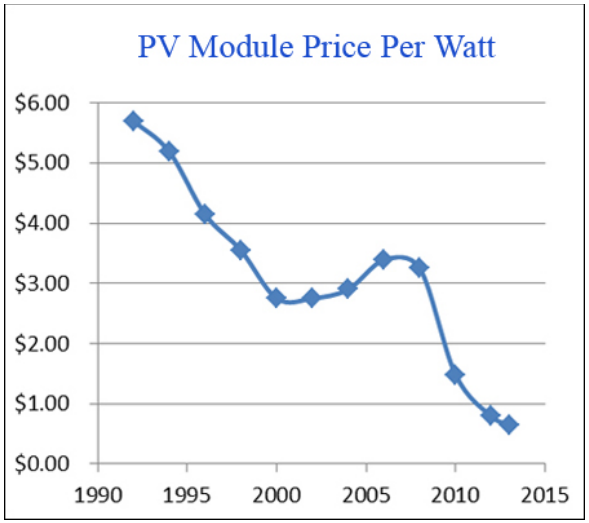
Module Encapsulation

Photovoltaic System

Source: McGehee, Energy Seminar 2014

Why silicon PV still expensive?





http://solarcellcentral.com/markets_page

c-Si production

- High temperature
- Energy-intensive

c-Si consumption

- Indirect band semiconductor
- Low absorption coefficient
- Silicon thickness (~200um)

Power conversion efficiency

- Lab efficiency ~25%
- Module efficiency ~18%

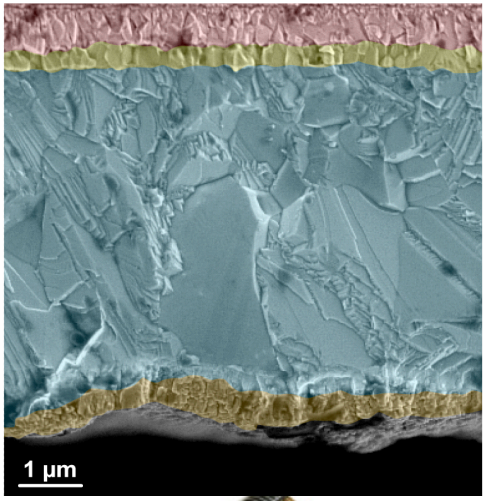
Installation cost

- Rigid, heavy-weighted

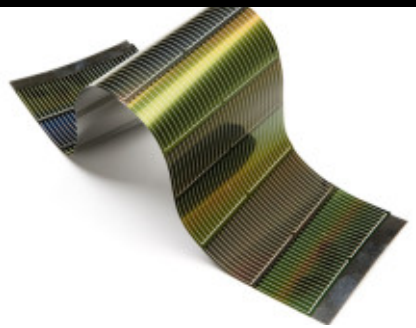
Thin film PVs

Thin film PVs use direct band gap semiconductors as light absorber

- CdTe, Amorphous Si, CIGS, GaAs…



SnO_2
CdS
CdTe
ZnTe:Cu
Ti



Pros:

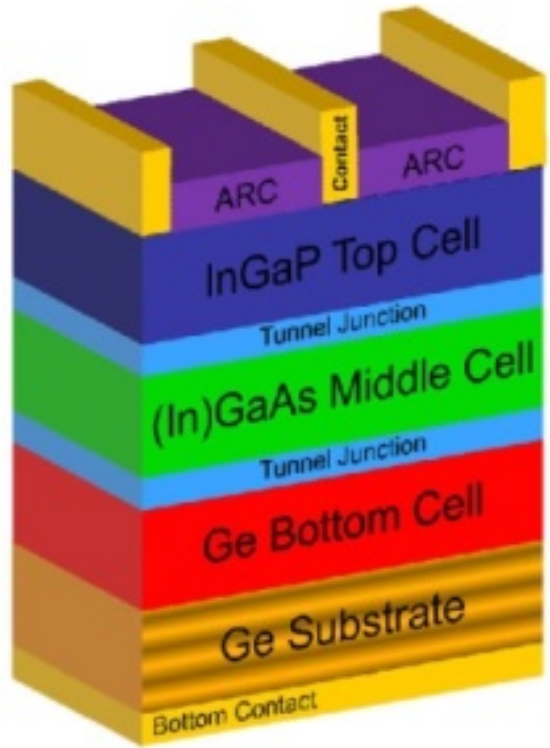
- Film thickness: 100 nm to 10 um
- Lower processing temperature
- Light weight, flexible

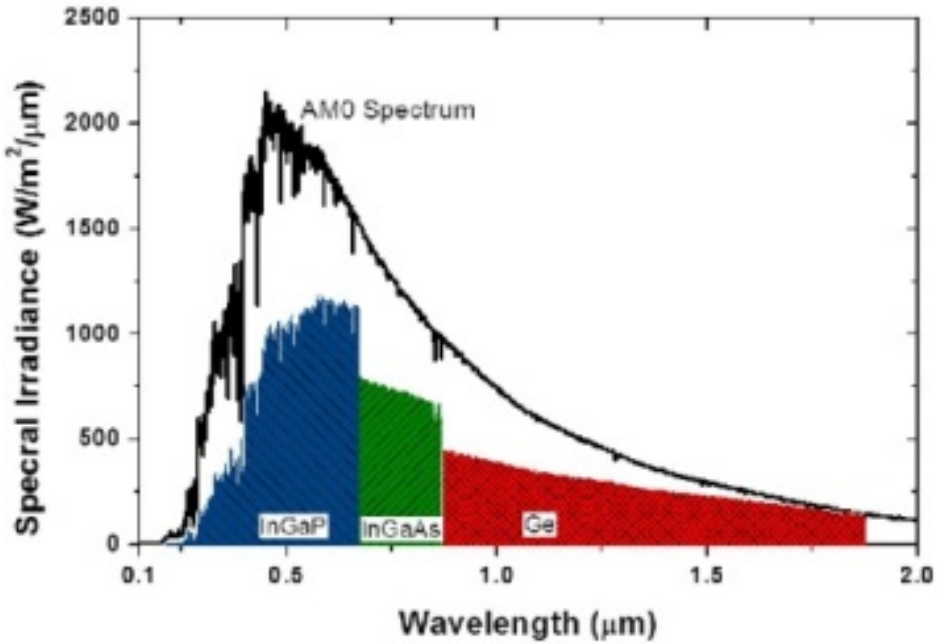
Cons

- Less abundant elements
- More complicated structure
- Vacuum processing
- Lower efficiency

Thin film PVs are also expensive

Multijunction PV





High efficiency: 40%
Extremely expensive

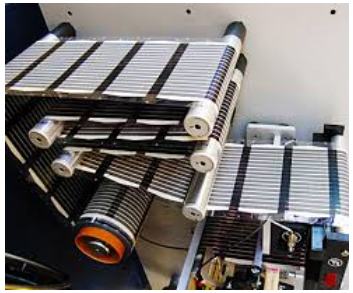
D. Forbes and S.Hubbard, SPIE Newsroom, 26 July 2010,

How to bring the PV cost down?

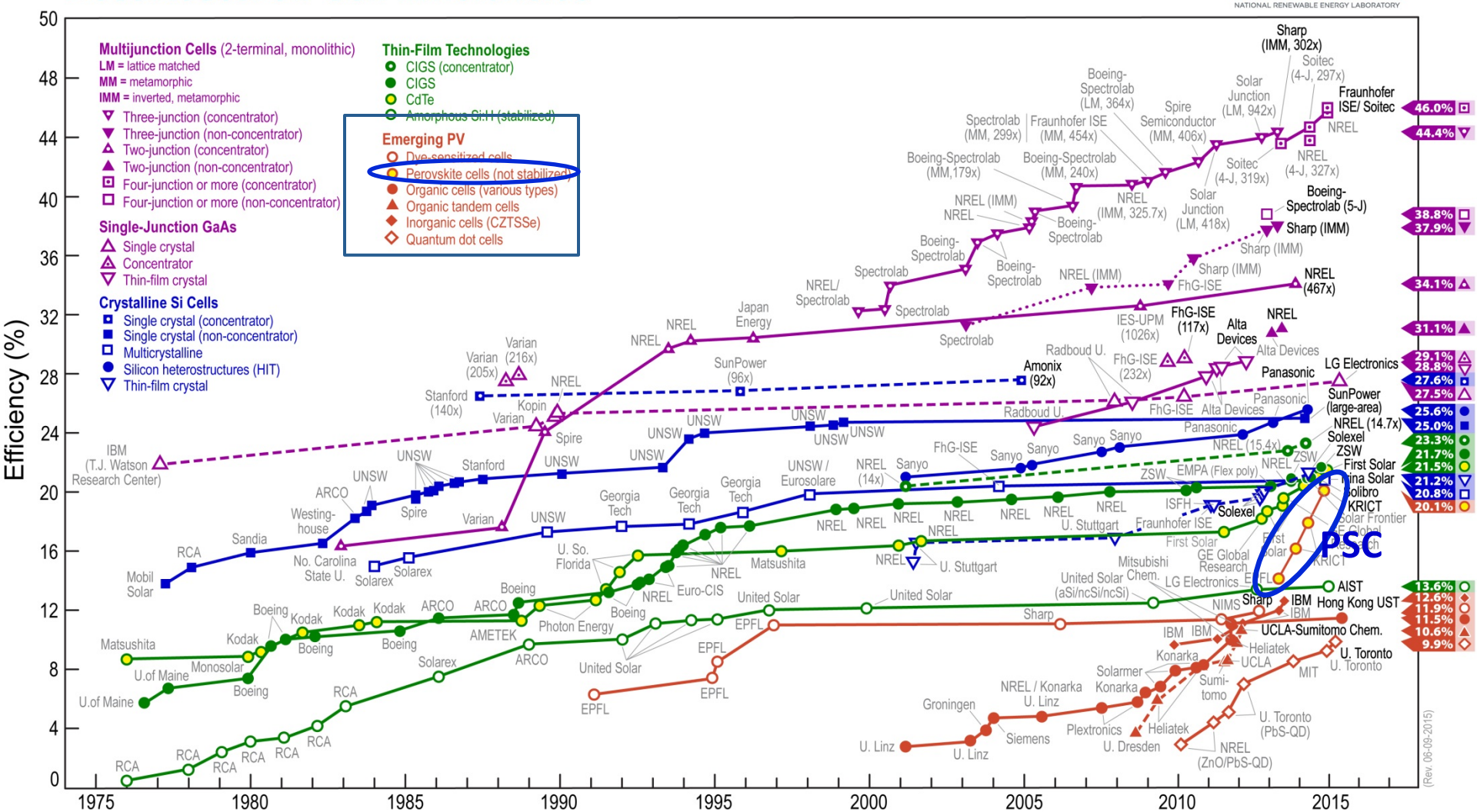
- Earth abundant elements
- Inexpensive fabrication
  - low-temperature
  - solution- processing
  - roll-to-roll manufacturing
- High efficiency
- Easy installation
  - light weight
  - flexibility

Emerging PVs:

- Dye sensitized solar cells (DSC)
- Organic Solar cells
- Quantum dot solar cells
- CZTS solar cells
- Perovskite solar cells (PSC)

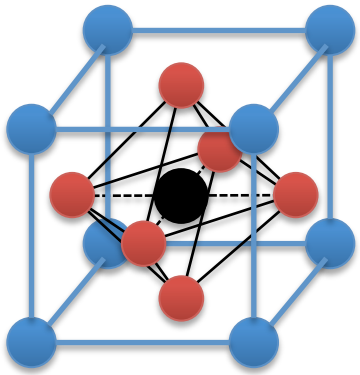


Best Research-Cell Efficiencies

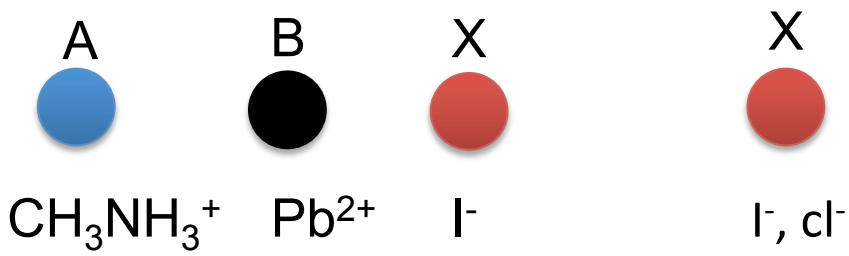


http://www.nrel.gov/ncpv/

Organometal Halide Perovskites



Perovskite
ABX_3 ($CaTiO_3$)



$CH_3NH_3PbI_3$

$CH_3NH_3PbI_{3-x}Cl_x$

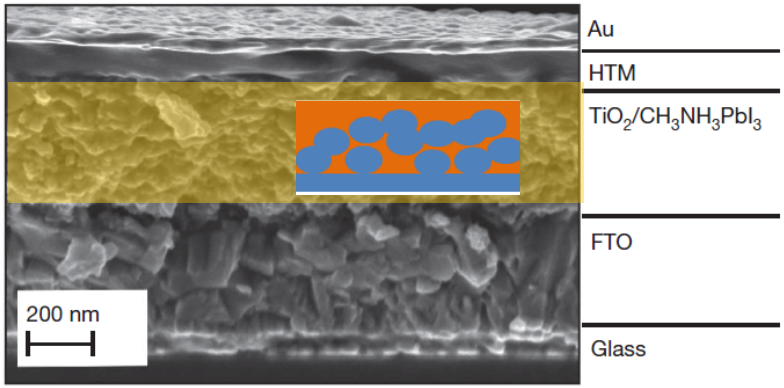
- ✓ Low temperature
- ✓ Solution processing
- ✓ Earth abundant elements

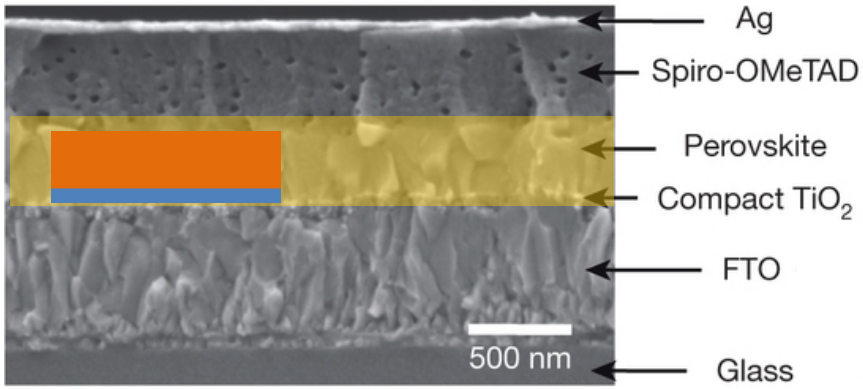
- ✓ High absoption
- ✓ Small exciton binding energy
- ✓ Excellent charge mobilities

J. Phys. Chem. Lett., **2013**, 4(15), pp 2423-2429

Perovskite solar cells

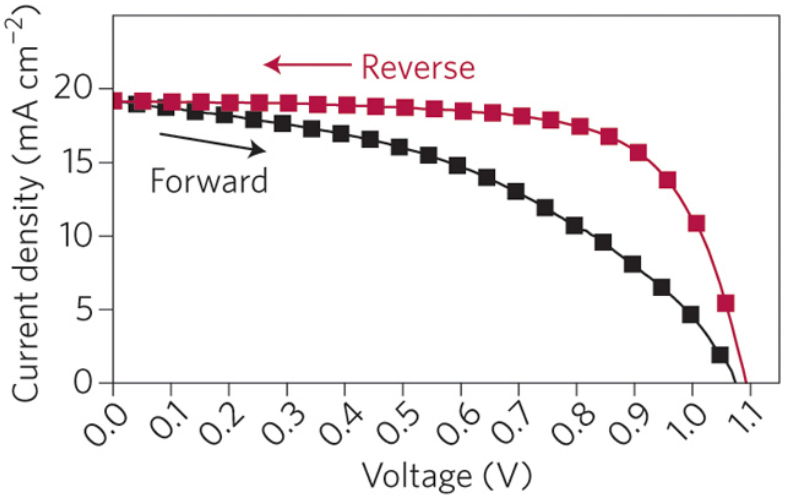
Mesoporous (DSC) vs Planar (thin film PV)





Challenges:

- Device structure
- Hysteresis
- "Lead" issue
- Stability



Snaith et al, Science 338, 643–647 (2012)
Grätzel et al, Nature 499, 316-320 (2013)

Snaith et al, Nature 501, 395- 398 (2013).

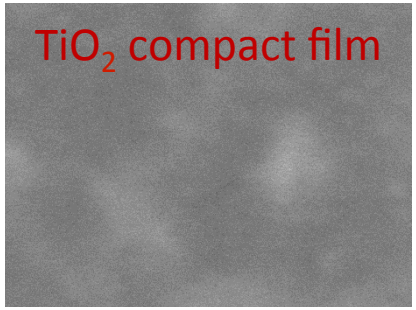
VFP Research: The role of TiO_2 Nanopaticles

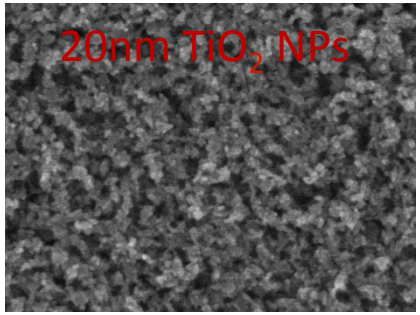
To examine the effect of TiO_2 NPs on perovskite film morphology, crystal structure, optical and electronic properties, and device performance

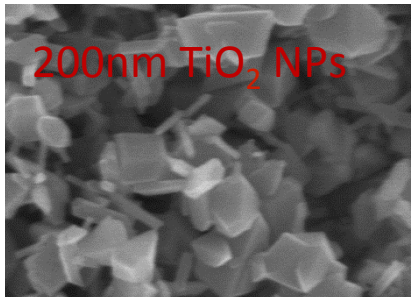
- Perovskite light absorber: $CH_3NH_3PbI_{3-x}Cl_x$
- TiO_2 :compact film, 20nm NPs, 200nm NPs

Device fabrication

- Film deposition: one step spin coating
- ETM: TiO_2 compact layer
- HTM: Spiro-OMeTAD
- Electrodes: Ag, FTO glass

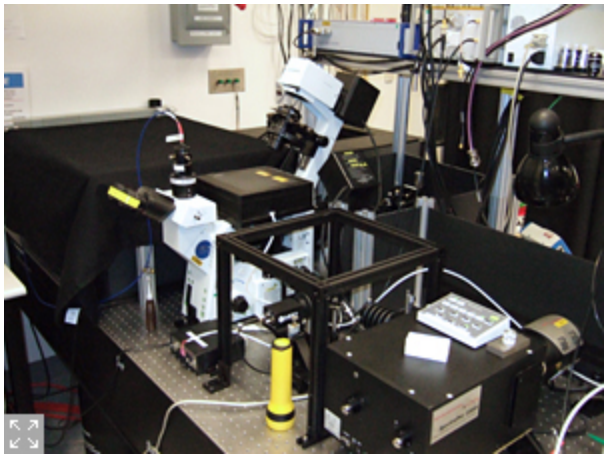


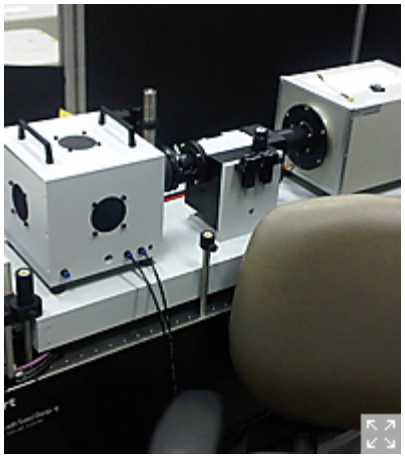




500nm

User facilities at CFN



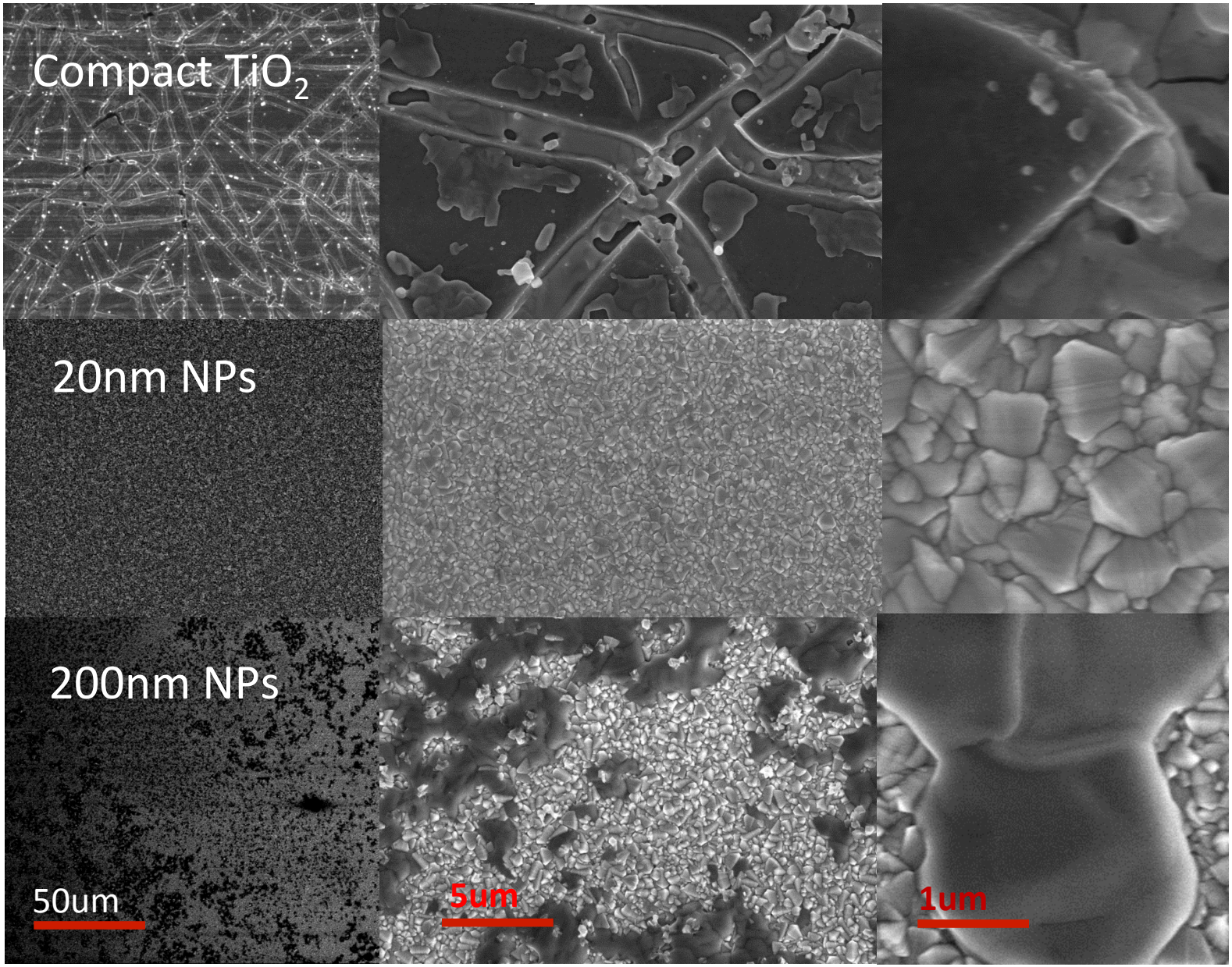


Time-resolved Confocal Microscope

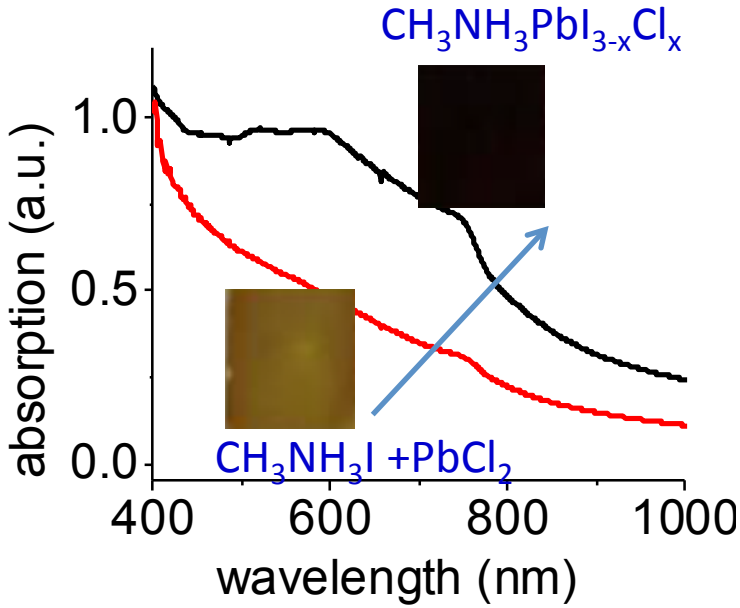
Hitachi s4800 SEM

Solar cell fabrication systems

Film morphology

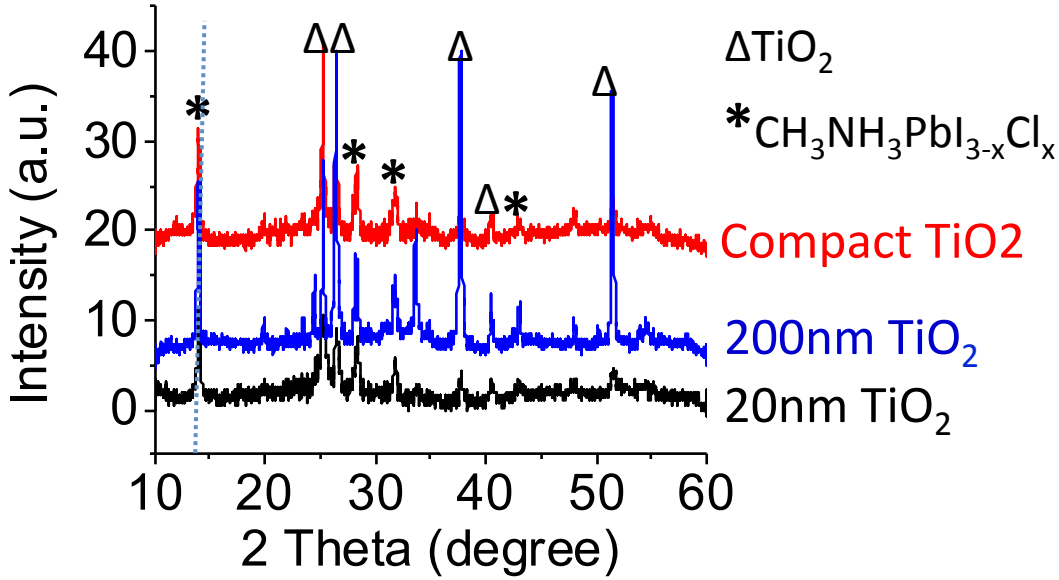


Crystal Structure



Annealing time (100°C)

- 20nm TiO_2: 5min
- 200nm TiO_2: 30min
- Compact TiO_2: 1h

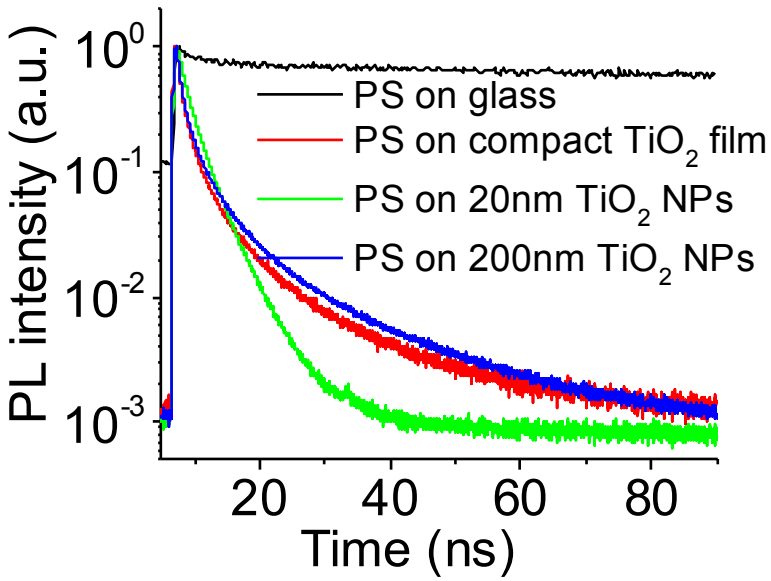


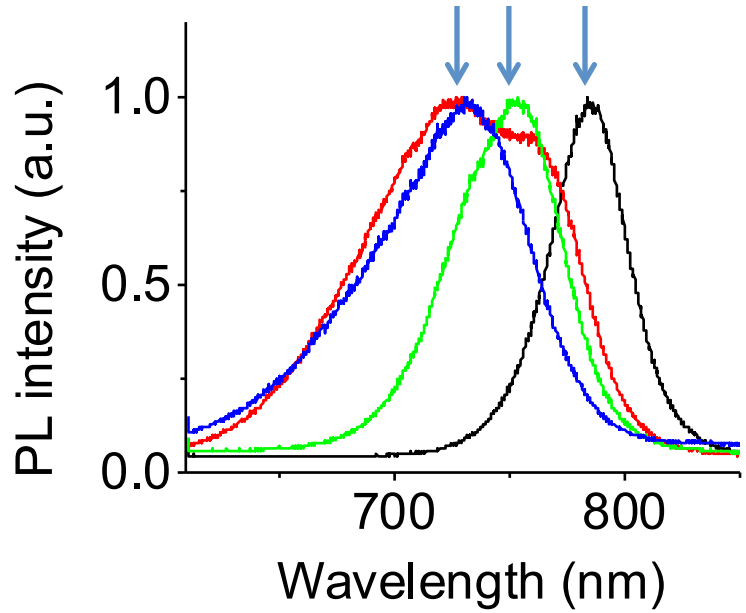
Peak position

20nm > 200nm > compact

TiO_2 NPs may slightly change the crystal structure of $CH_3NH_3PbI_{3-x}Cl_x$

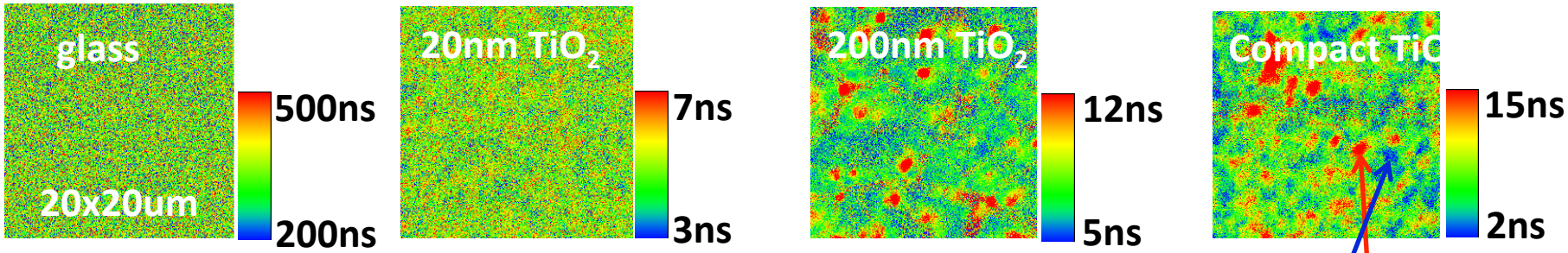
PL of Perovskite films

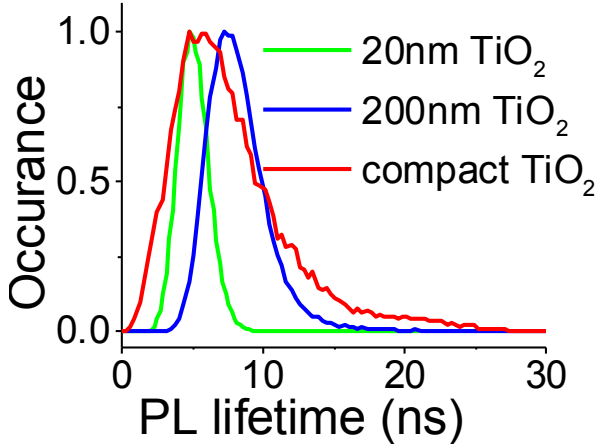


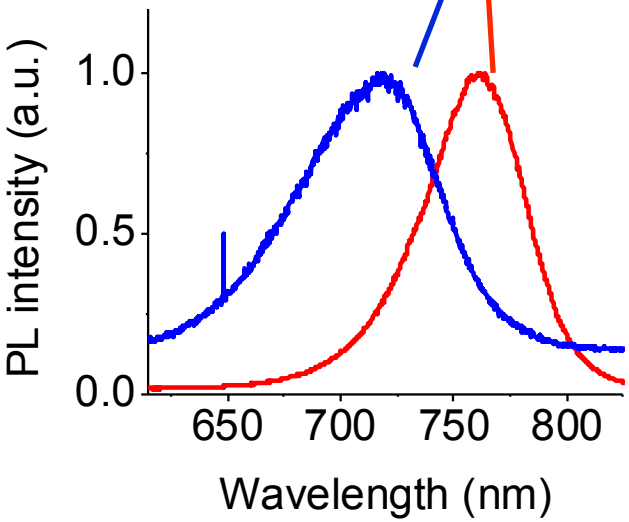


- Significant quenching of PL lifetime indicates efficient electron transfer
- Long lifetime components in compact and 200nm TiO_2 samples
- Variations in spectra (peak position and band width) suggest different crystal/defects structures

Fluorescence lifetime imaging







Two different perovskite structures !

Correlation between lifetime and spectra peak position

Acknowledgements

- DOE Visiting Faculty Program (VFP)

- Center for Functional Nanomateirals (CFN), BNL
  - *Mircea Cotlet, Chang-Yong Nam, Gwen Wright, Mingzhao Liu, Huidong Zang, and many others*

- Office of Education Program (OEP), BNL
  - *Neol Blackburn, Cindi Biancarosa, Sal Gonzalez, and the others*