

Printable Solar Cells



Peter Dowben

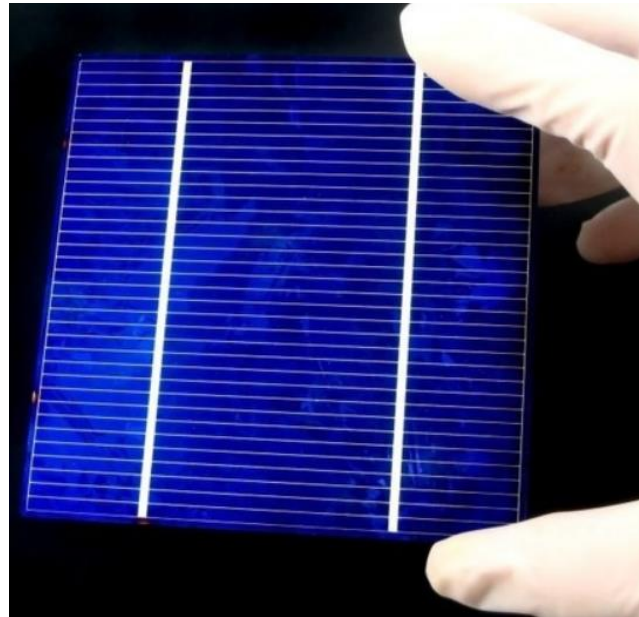
Department of Physics and Astronomy



UNIVERSITY OF
Nebraska
Lincoln

Silicon Solar Cell

It is cheap, it is reliable and it is the standard



Why look any farther ???

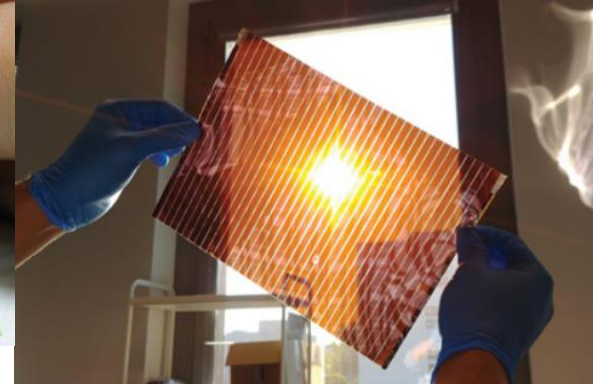
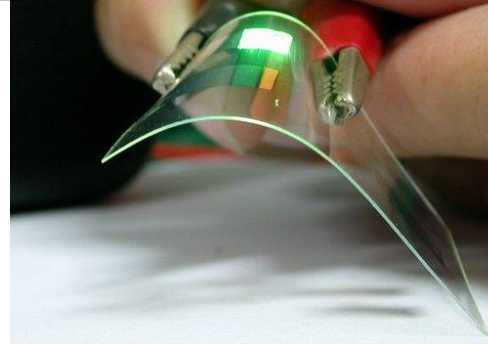
Low cost High Efficiency: Inkjet printing for Photovoltaic Windows

Howard L. Hawks Hall



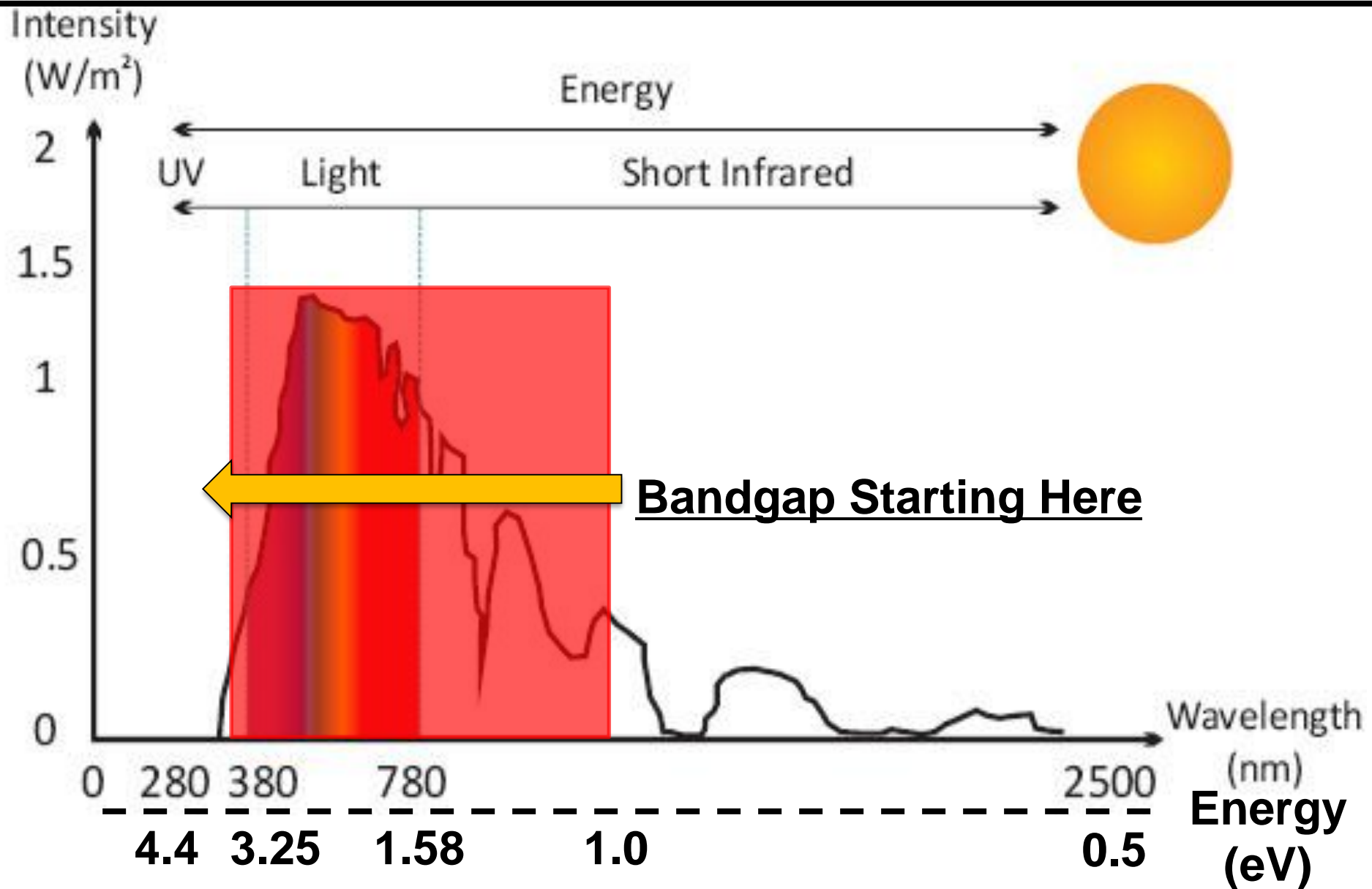
Low weight
500 g/m²

Semi Transparent

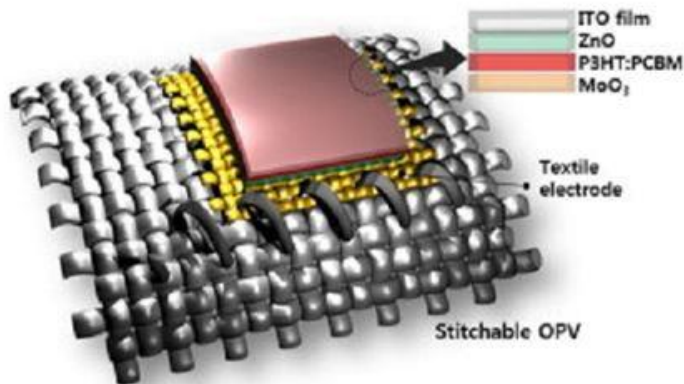


Shadow Absorption Flexible Substrates

Covering the Solar Spectrum

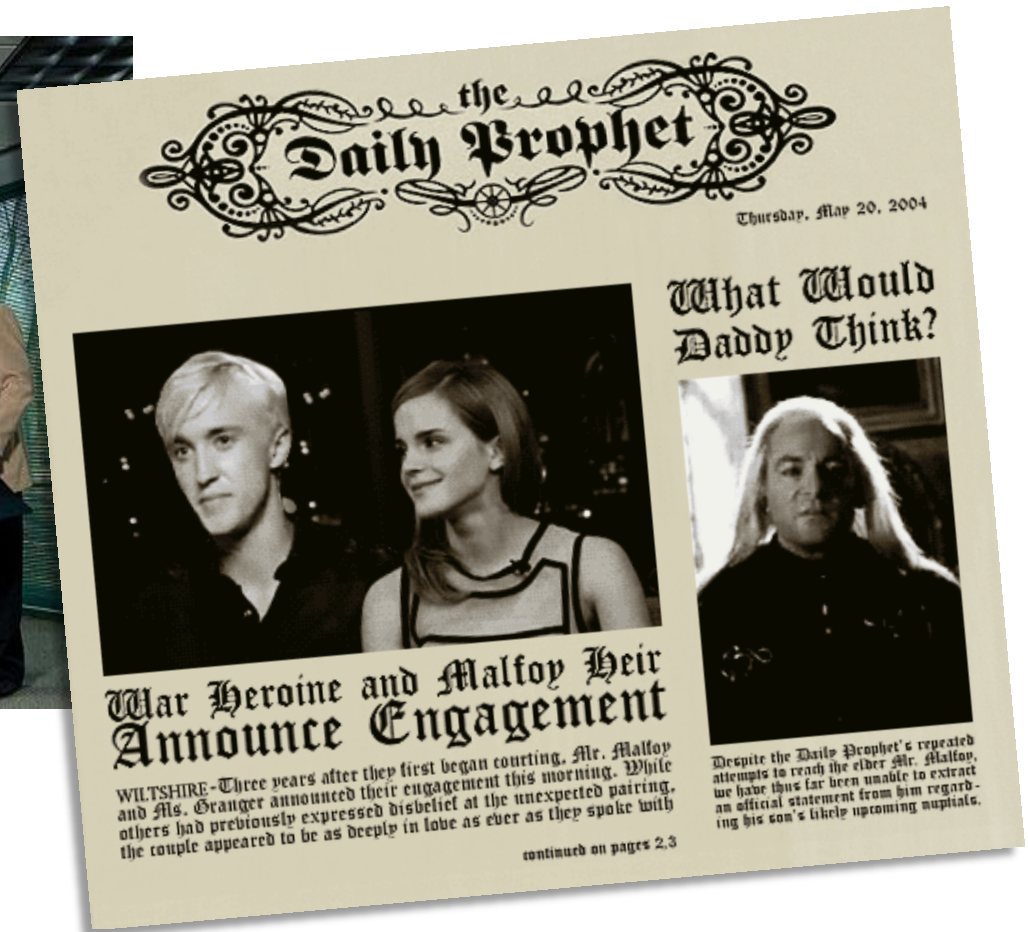


Photovoltaics from Organics



Organics are in principle cheap, flexible, bendable, and amenable to a variety of high throughput production methods

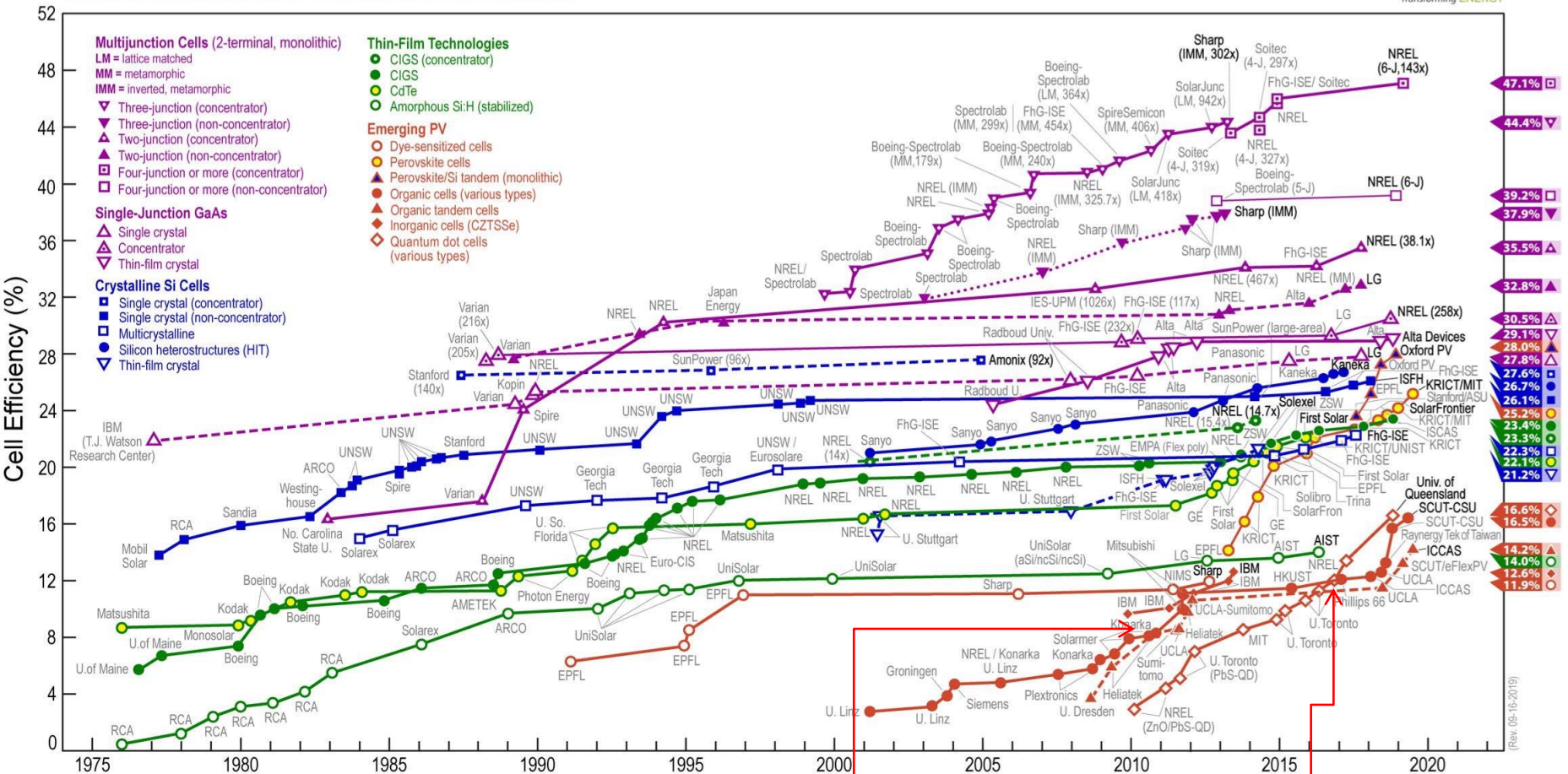
Not just solar cells, but displays too



Motion Articles on Paper

Organic Photovoltaics are emerging and promising, with some problems...

Best Research-Cell Efficiencies



Red are the organic solar cells

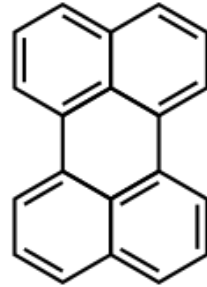
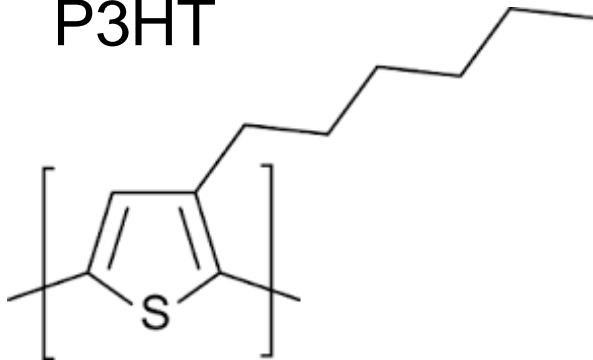
And these are not very stable

Problems with Organic Photovoltaics

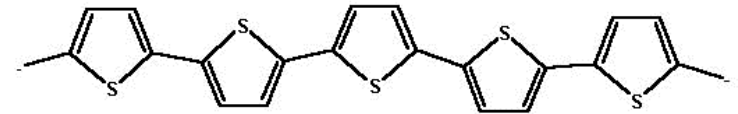
- Organic solar cells need to be stable! They have to work for a long, long time and survive in harsh conditions.
 - solution: need additives to stabilize the organics
- They need to be made more efficient! Now efficiency is low (about 5%) or high (23%) but in materials not very stable. (high efficiency materials are the ones that degrade in sunlight)
 - solution: need additives to stabilize the organics – these will be dipolar molecules, and graded multilayers could improve efficiency a lot
- The organic solar cells need to be scalable! Can the materials be manufactured cheaply on a large scale?
 - Solution: Deposition from solution

Organic Semiconductors and Conductors

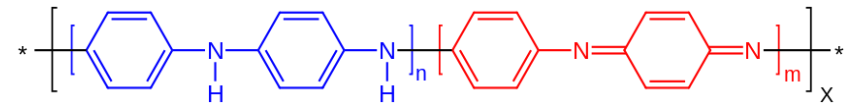
Poly(3-hexylthiophene-2,5-diyl)
P3HT



Perylene



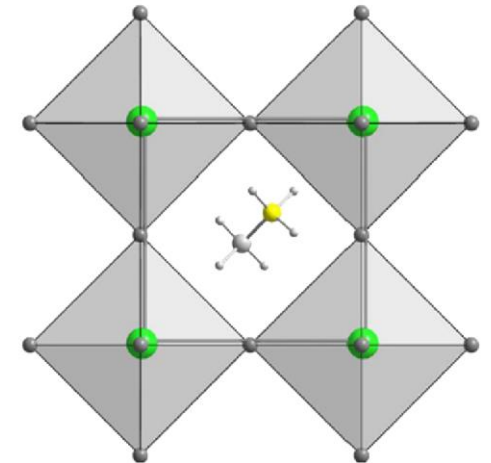
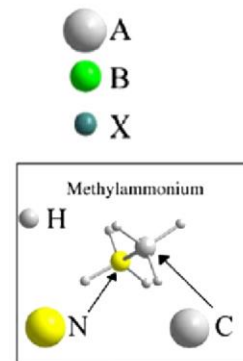
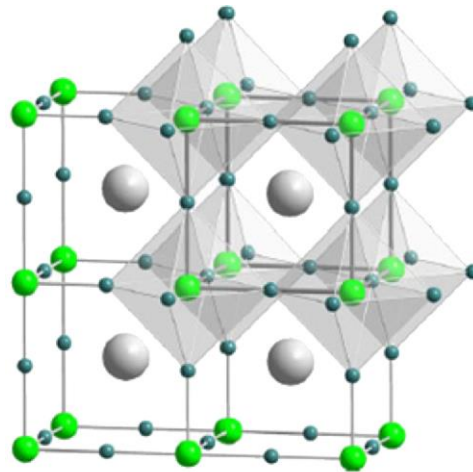
Polythiophene



Polyaniline

organolead
trihalide

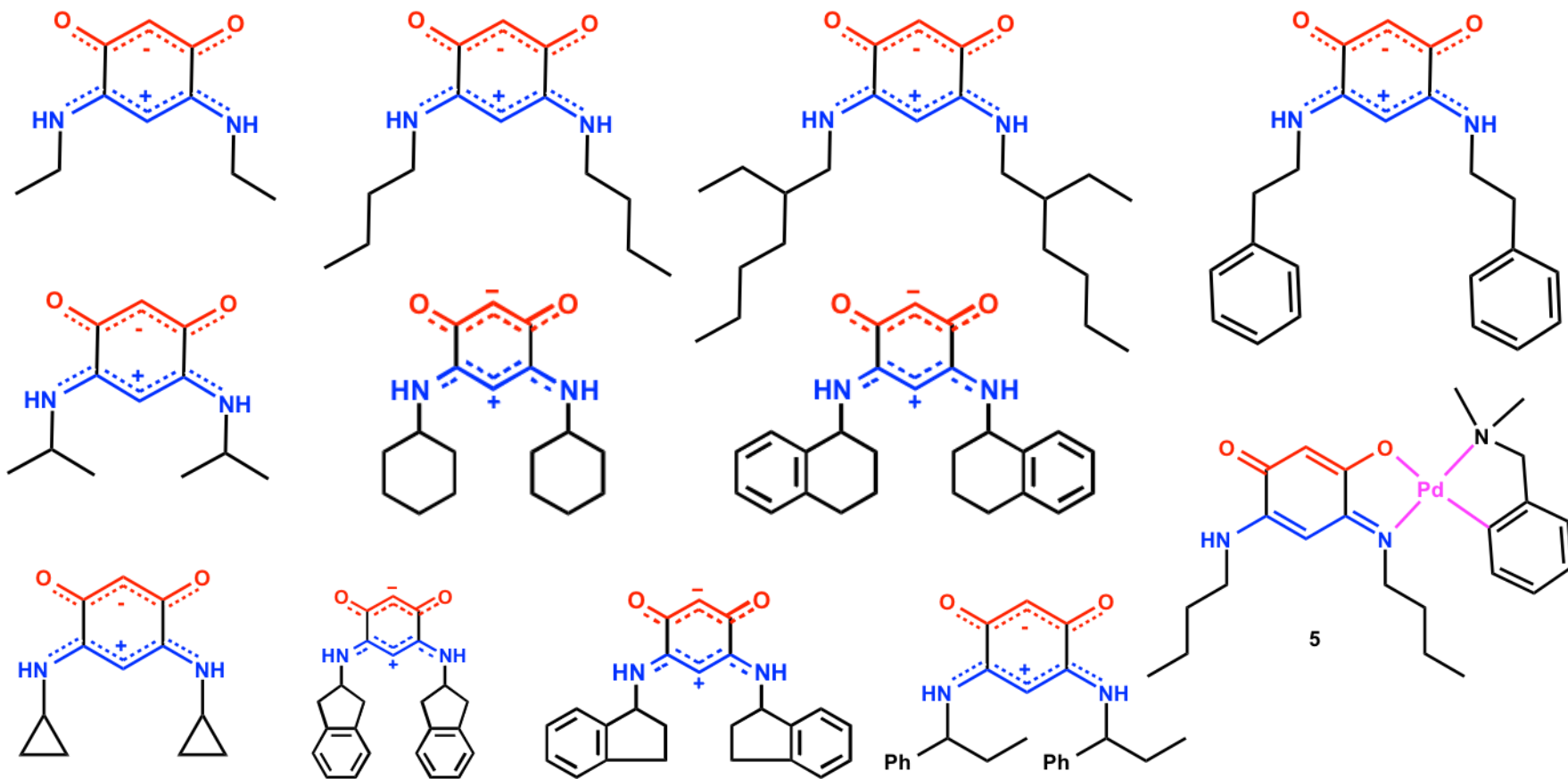
$\text{CH}_3\text{NH}_3\text{PbX}_3$
(organic perovskite)



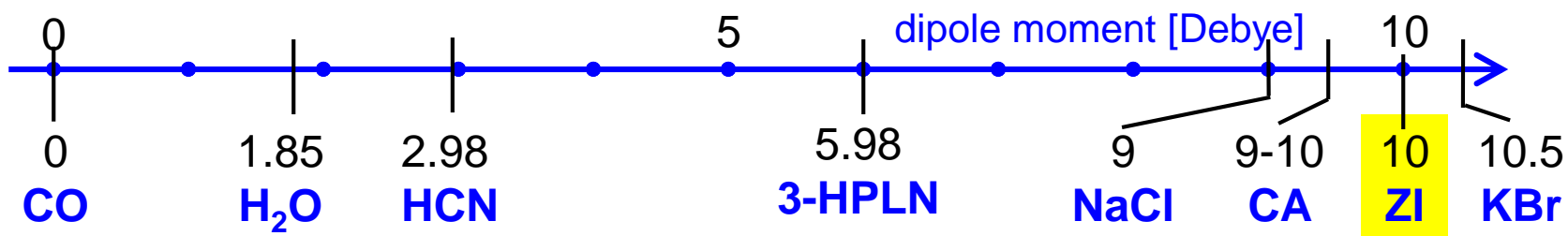
D. Shi, Peter A. Dowben, O. M. Bakr, et al, "Exceptionally low trap-state density and long carrier diffusion in room-temperature grown MAPbBr₃ perovskite single-crystal wafers", *Science* **347** (2015) 519-522

“Modifiers”

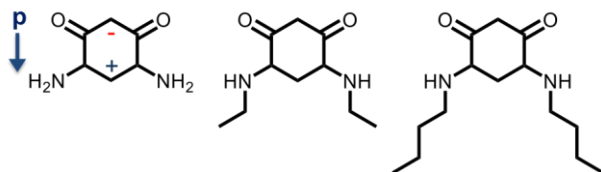
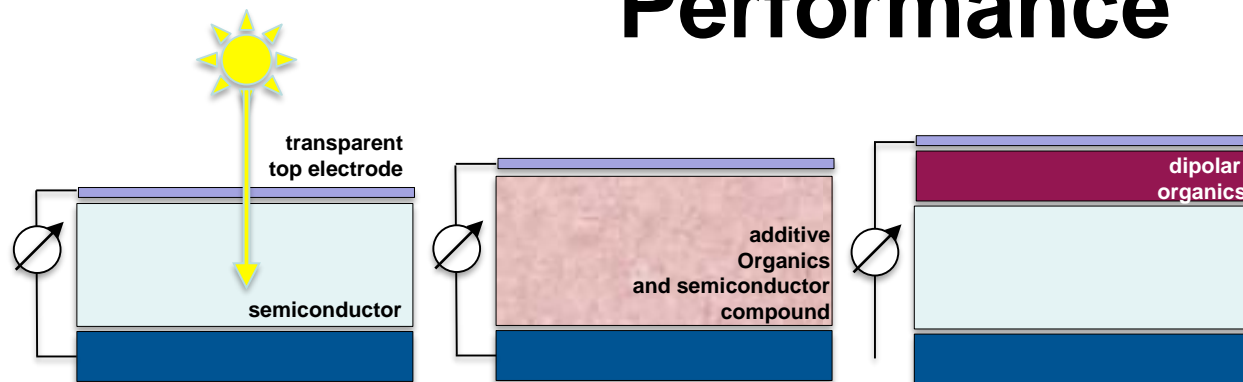
We have over 50 different kinds of p-benzoquinone monoimine zwitterions



5

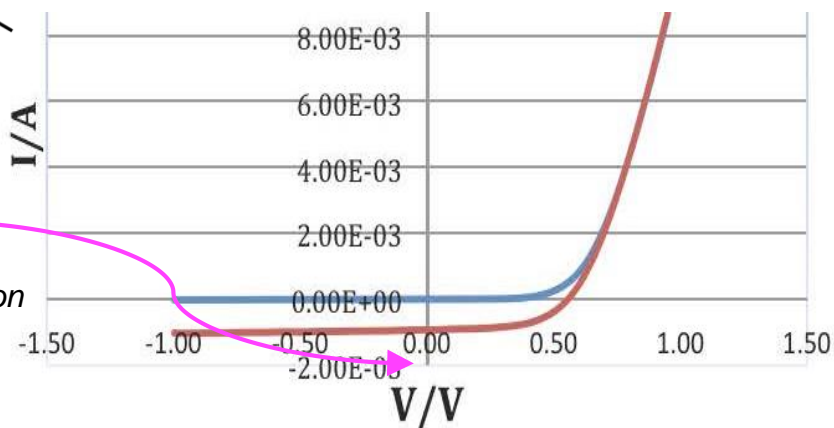


Demonstration of Additives on PV Performance



The signature of a successful organic solar cell combination: current at zero applied volts.

Enders, Dowben, and Doudin; unpublished data for dipolar zwitterion molecule (where $R = C_4H_9$) in combination with the organic semiconductor PEDOT (Poly(3,4-ethylenedioxythiophene)).



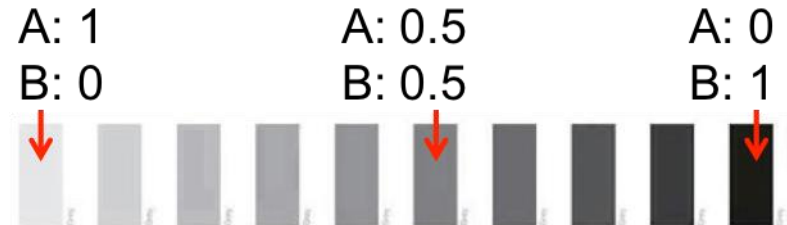
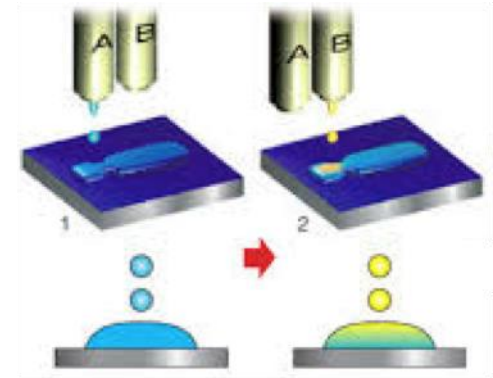
The additives enhance photo current generation!
But:
We still need to increase this current generation!

Dipolar molecules produce an intrinsic electric field that enhances the electron-hole separation in the semiconductor. This is new science!

Rapid Prototyping of Materials Combinations

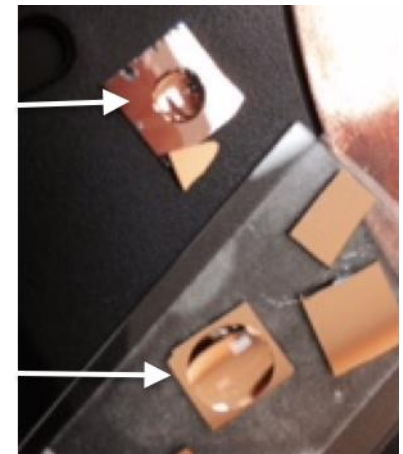


Rapid prototyping
with inkjet printer
technology
using a modified
inkjet printer

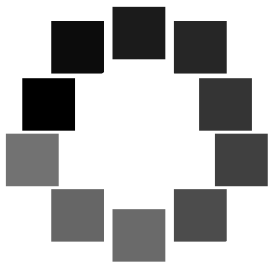


water droplet on
As-grown
Au film on Si

water droplet on
ozon-cleaned
Au film on Si



Ink



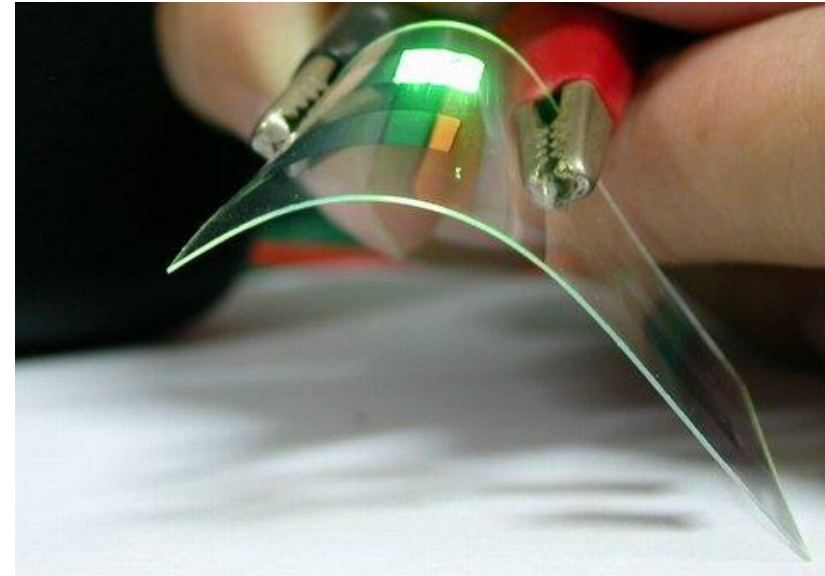
Template design for CD/DVD tray of printer



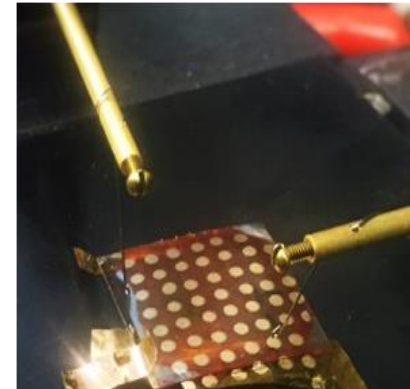
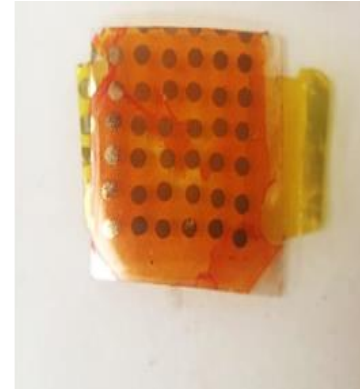
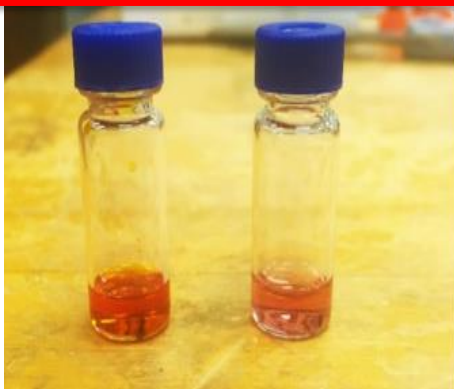
Grayscale ink printing (10 samples)



Cheap and Flexible

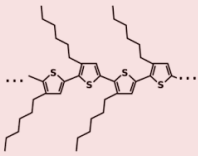
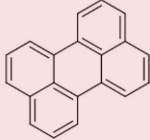
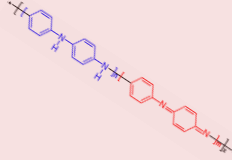
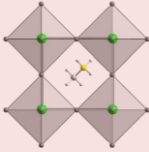
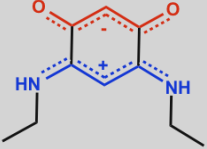


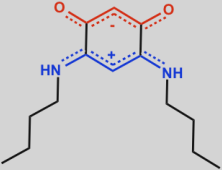

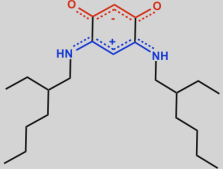



Simple Mass Production



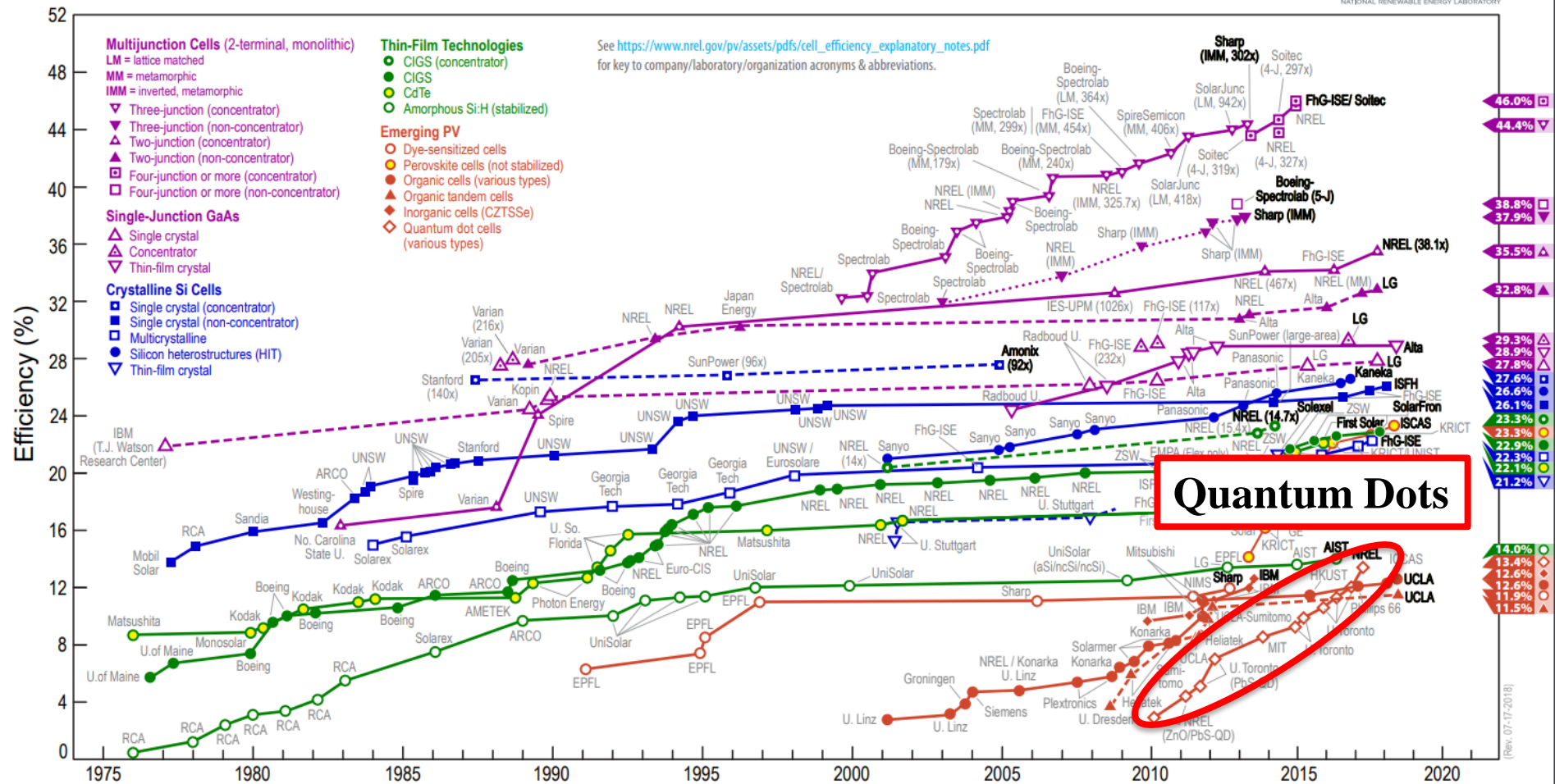
Organic Solar Materials

Modifiers

					...
					
					
					
...					

Where do Quantum Dot Solar Cells Rank?

Best Research-Cell Efficiencies

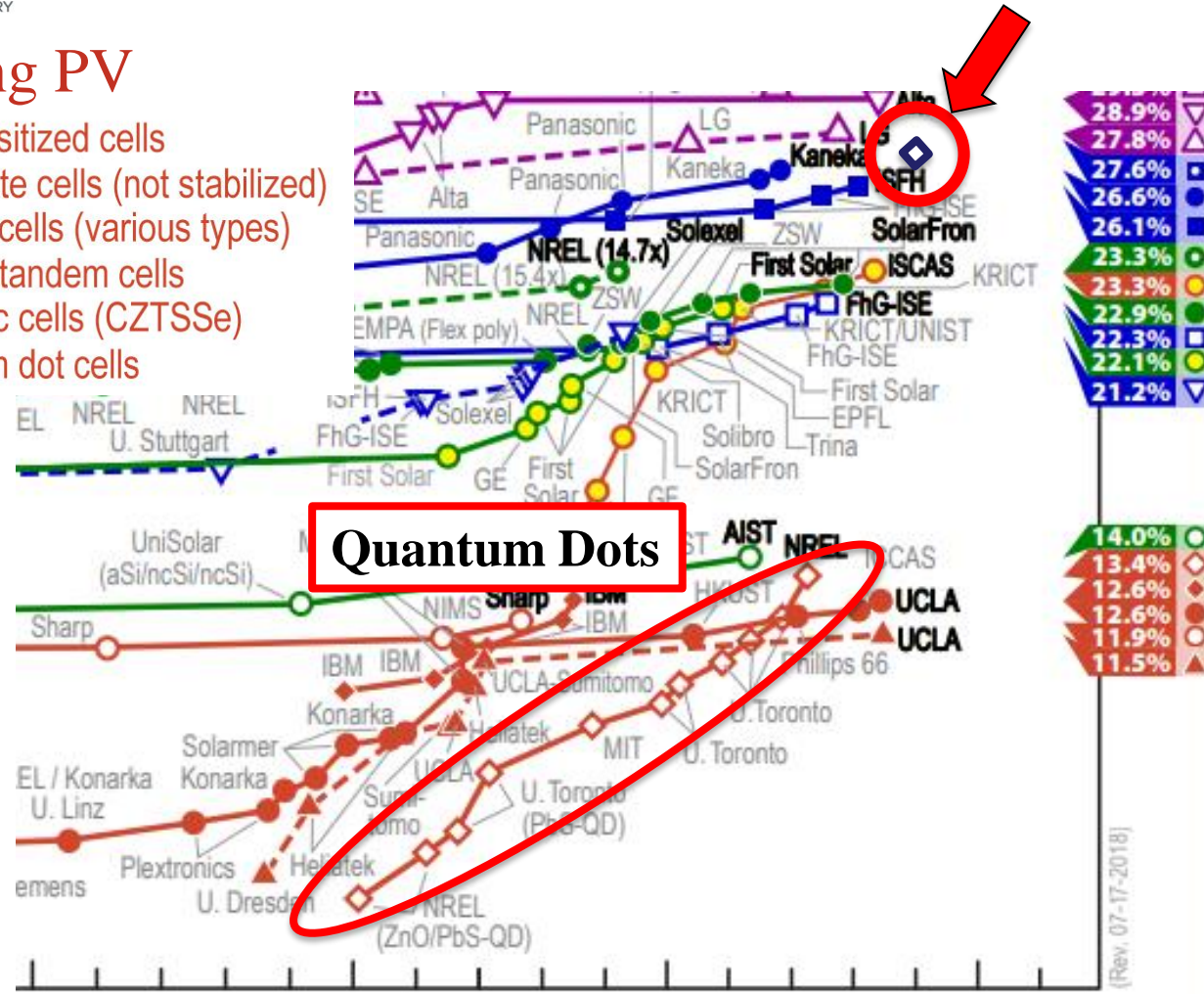


Our Best Devices

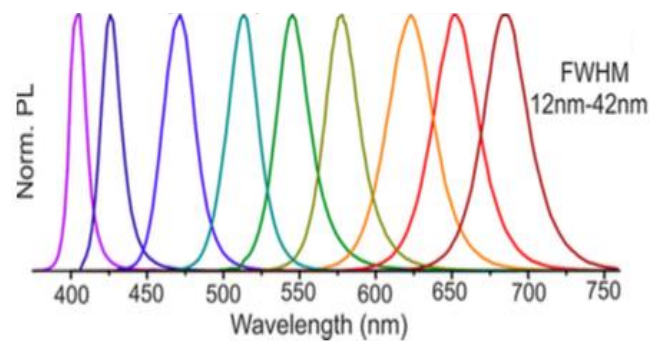
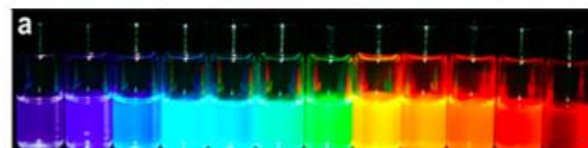
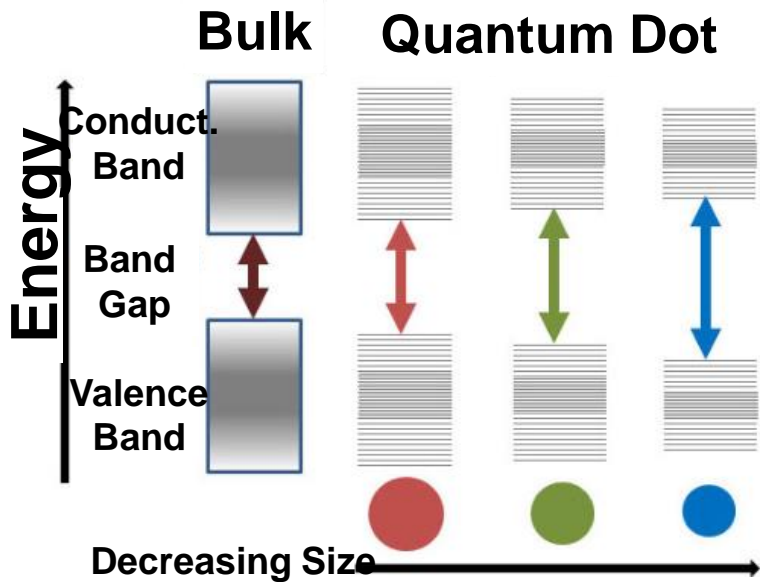
Emerging PV

- Dye-sensitized cells
- Perovskite cells (not stabilized)
- Organic cells (various types)
- ▲ Organic tandem cells
- ◆ Inorganic cells (CZTSSe)
- ◇ Quantum dot cells

Efficiency (%)



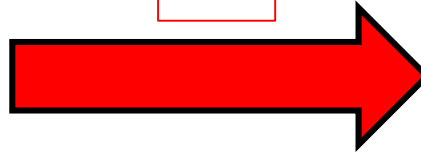
WE can tune the color by size or chemistry



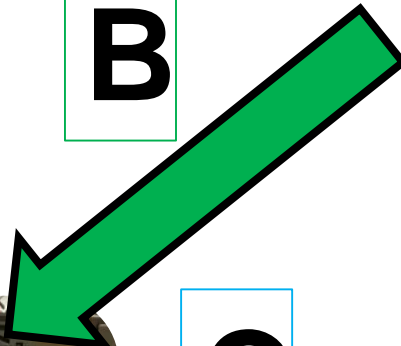
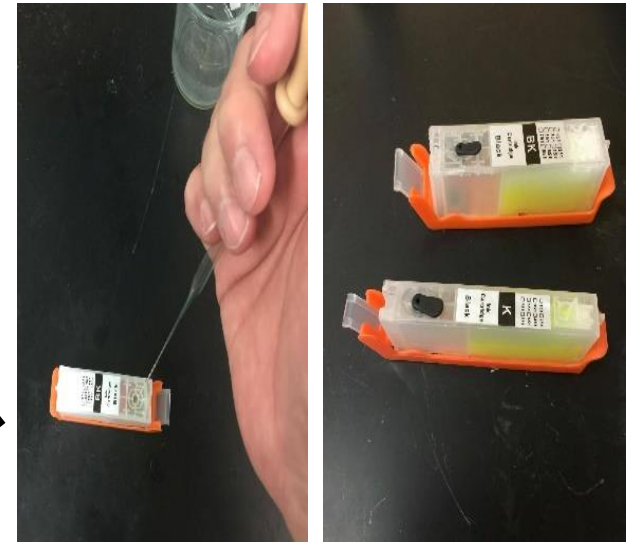
Inkjet Printing of Solar Cell Inks



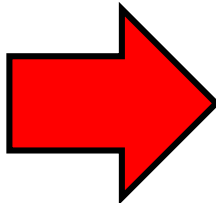
A



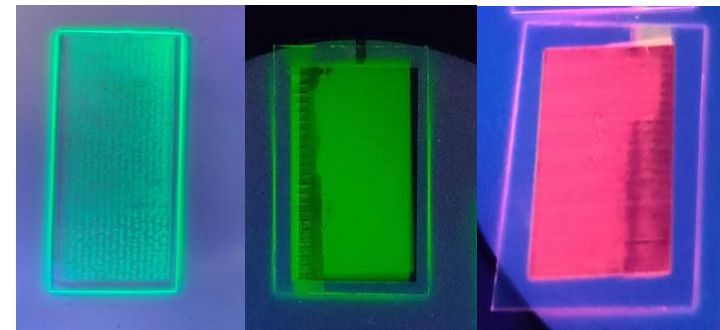
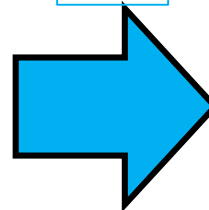
B



A

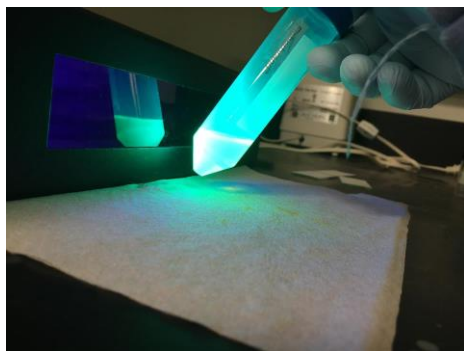
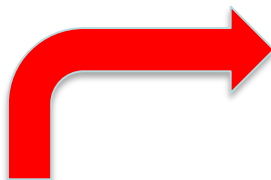


C



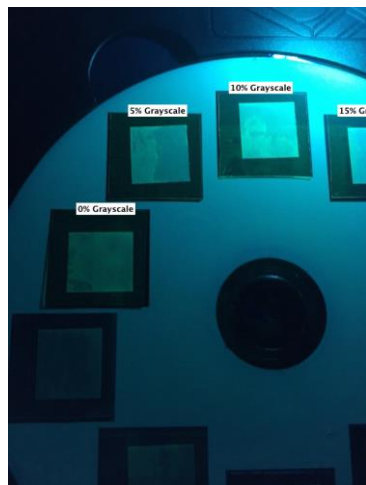
Applicability: "Printable" Solar Cells

Rapid prototyping
with inkjet printer
technology



Perovskite Synthesis

Inexpensive wet
lab solution-phase
synthesis of
 CsPbX_3 NCs



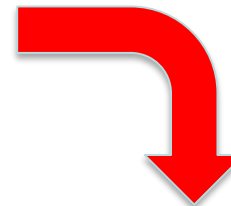
Inkjet Printing
of NCs in
solvent on
substrates



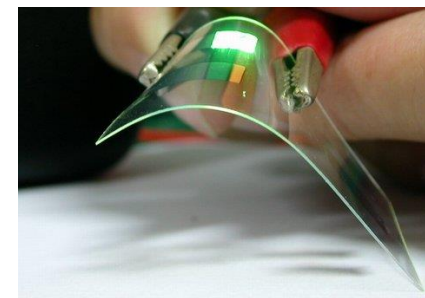
How to test all the possible
combinations to find the best
combinations for the most
successful organic photovoltaic ?



N



Constructing
Shapes using
printed NCs



Developing Thin-
Film Solar Cells
from printed
perovskite NCs

Efficiency is not every thing:

If you cover more surface area and generate more current at much lower cost, you win.

So a window you look through but is also a solar cell could be a BIG winner, even if not very efficient.



SAULE
TECHNOLOGIES



nanograde®




Heliatek
The future is light


Borun
New Material

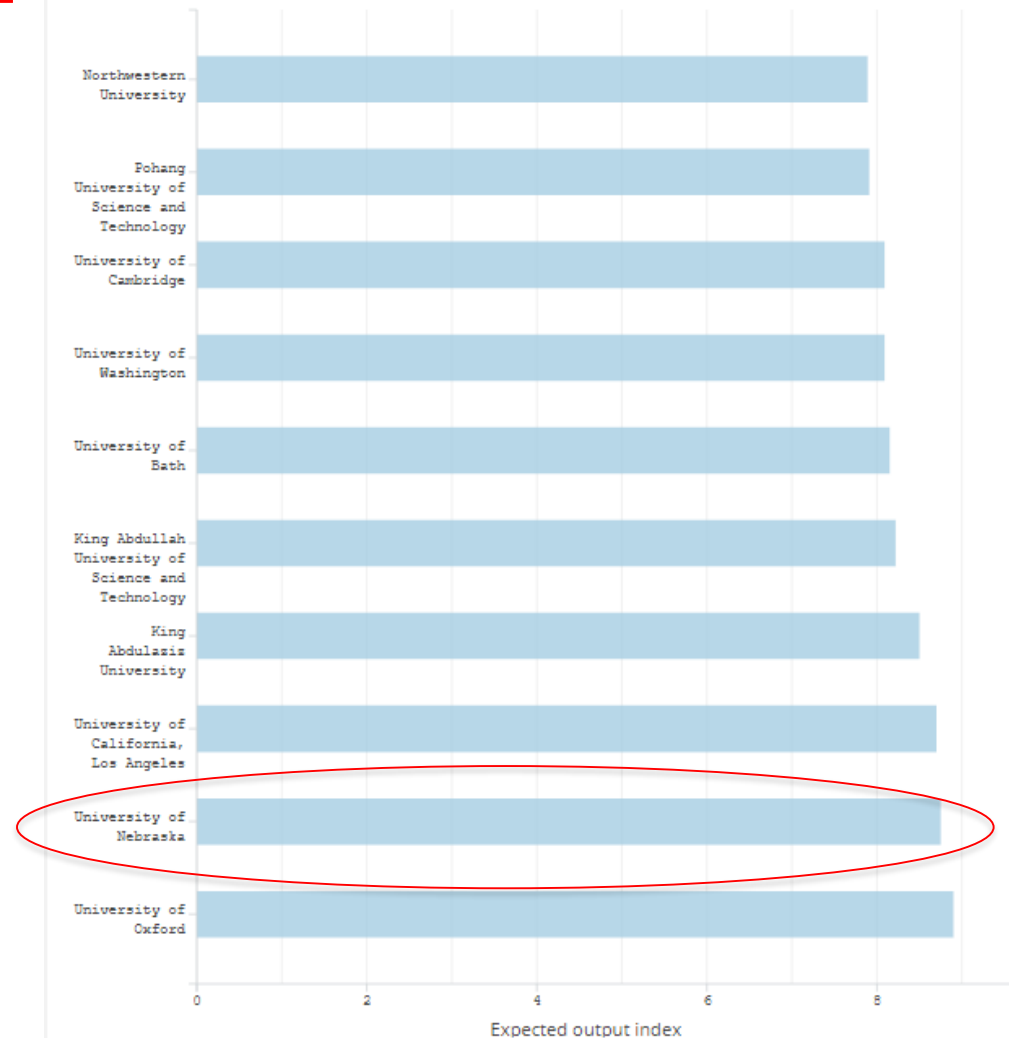
Top universities and researchers in perovskite solar cell research

In The News!

We are No. 2 in the world for novel materials in photovoltaic research

Top 10 universities in methylammonium lead perovskite solar cell research, 2014 to 2017

By expected output in top 10 per cent of most highly cited research for topic. World average = 1



Source: Elsevier/SciVal. Only academic institutions publishing at least 50 articles from 2014 to 2017 included.



Nebraska Public Power District

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