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Nanotechnology Applications

E SC 215

Unit 5
Organic Solar Cells

Lecture 1
Application of Nanotechnology to Solar Cells

Outline

- Introduction to solar energy conversion
- Overview of technology and materials
- Processing sequence
- Characterization of devices
- Trends for the future

MRS Bulletin 2005, 30(6), 412.

MATERIAL MATTERS

Future Global Energy Prosperity: The Terawatt Challenge

Richard E. Smalley

Top 10 World Issues

1. Energy
2. Water
3. Food
4. Environment
5. Poverty
6. Terrorism and war
7. Disease
8. Education
9. Democracy
10. Population

"To give all 10 billion people on the planet the level of energy prosperity we in the developed world are used to, a couple of kilowatt-hours per person, we would need to generate 60 terawatts around the planet – the equivalent of 900 million barrels of oil per day."

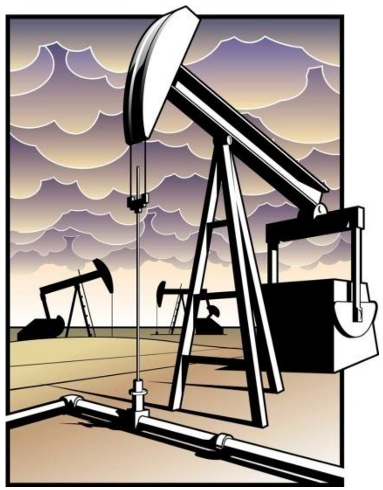
"When we look at a prioritized list of the top 10 problems, with energy at the top, we can see how energy is the key to solving all of the rest of the problems – from water to population."

-Richard E. Smalley
Nobel Laureate in Chemistry (1996, for the discovery of fullerenes)

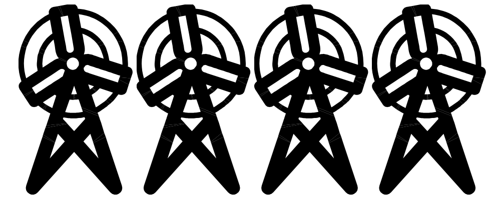
How do we make TW of power?

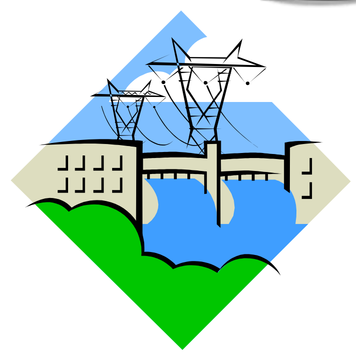
Fossil Fuels
(non-renewable)

Oil
Coal
Natural Gas

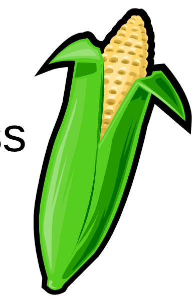


Renewables





Solar
Wind
Hydroelectric
Sustainable Biomass



Nuclear
(non-renewable)

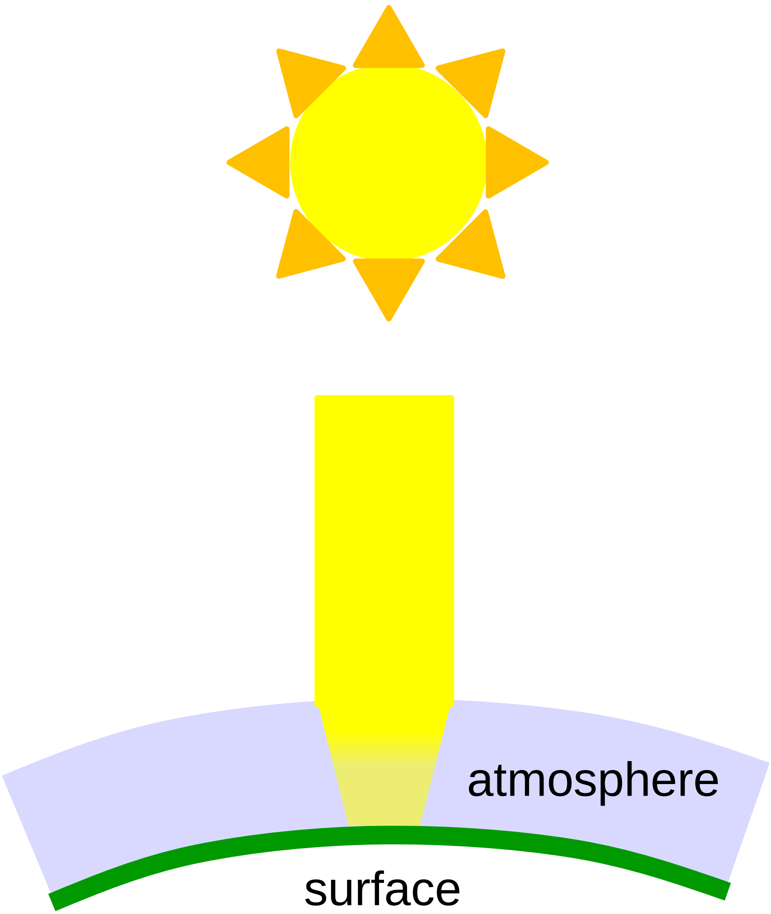
Solar Radiation

$1366\ W/m^2$: Power density of the sunlight striking the Earth's outer atmosphere. Known as the solar constant.

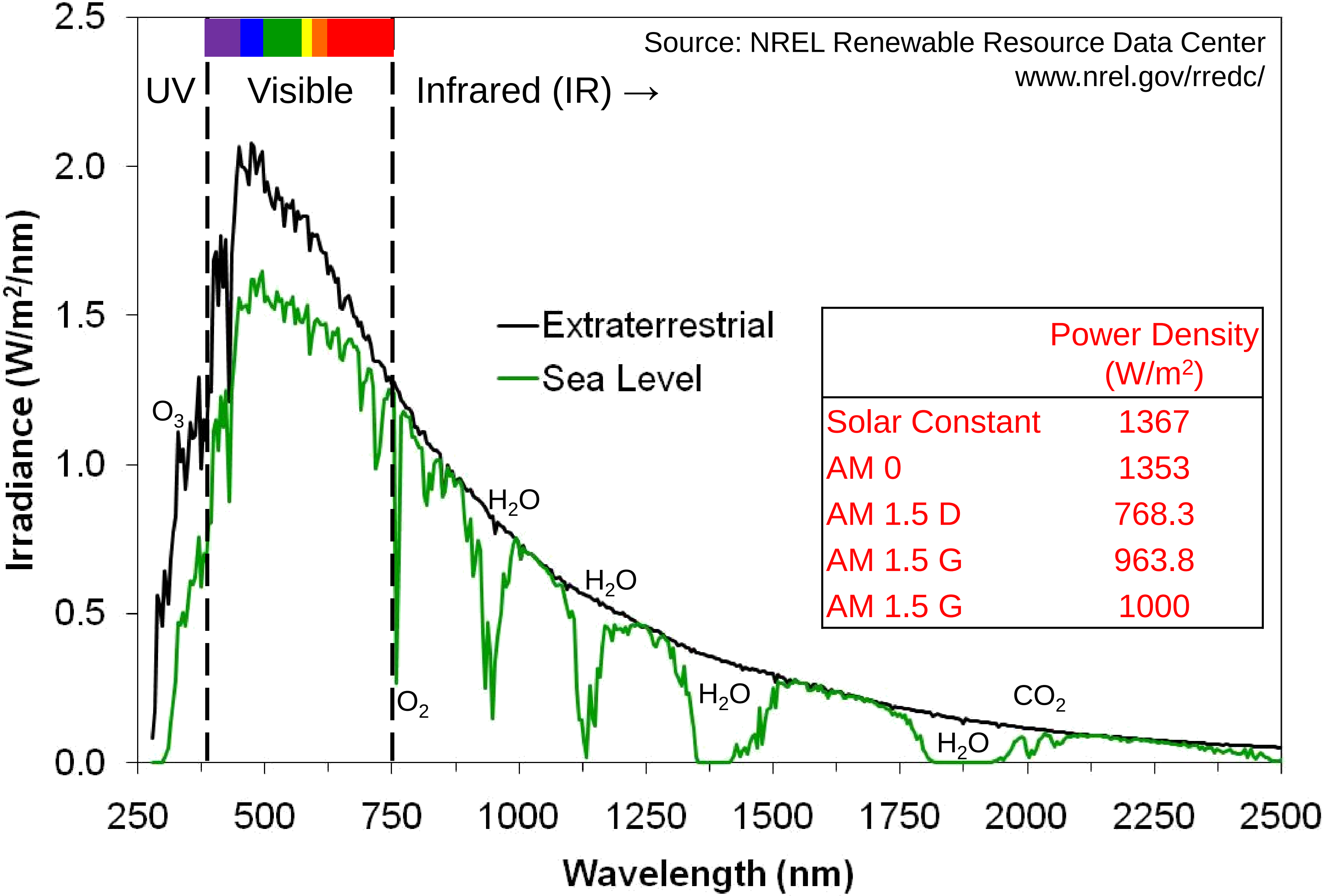
$1000\ W/m^2$: Power at Earth's surface on a clear day with the sun directly overhead.

$300\ W/m^2$: Approximate amount available on Earth when averaged over 24 hours.

153,000 TW …way more than enough!



The Solar Spectrum



	Power Density (W/m^2)
Solar Constant	1367
AM 0	1353
AM 1.5 D	768.3
AM 1.5 G	963.8
AM 1.5 G	1000

Using the Sun's Energy

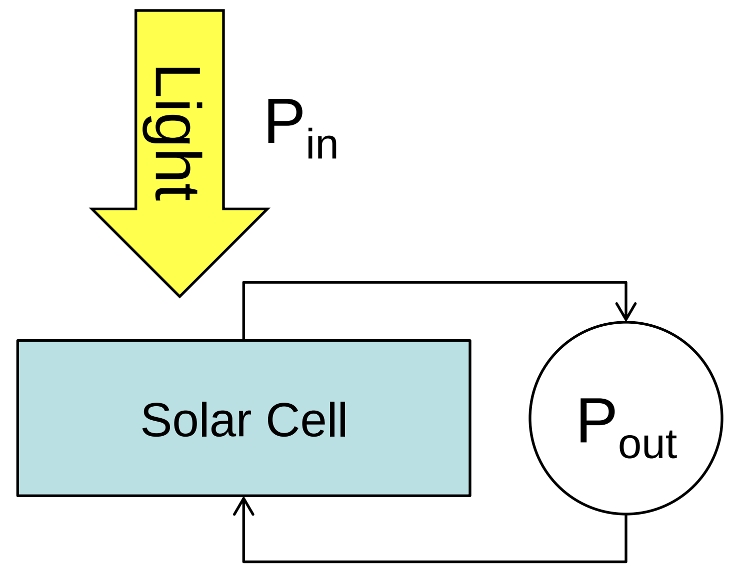
The basic processes in converting the sun's energy into usable electricity are:

1. Absorption of light
2. Creation of free charge carriers: e^- and h^+
3. Transport and collection of charge
4. Using the electrical energy
   - To power a device (e.g., a calculator)
   - To recharge a battery (energy storage)

Power Conversion Efficiency

- Abbreviated PCE
- Ratio of power density obtained from solar cell to the incident solar power density
- The incident light is often produced by a solar simulator and P_{in} is commonly fixed at 100 mW/cm^2

$$PCE = \frac{P_{out}}{P_{in}}$$



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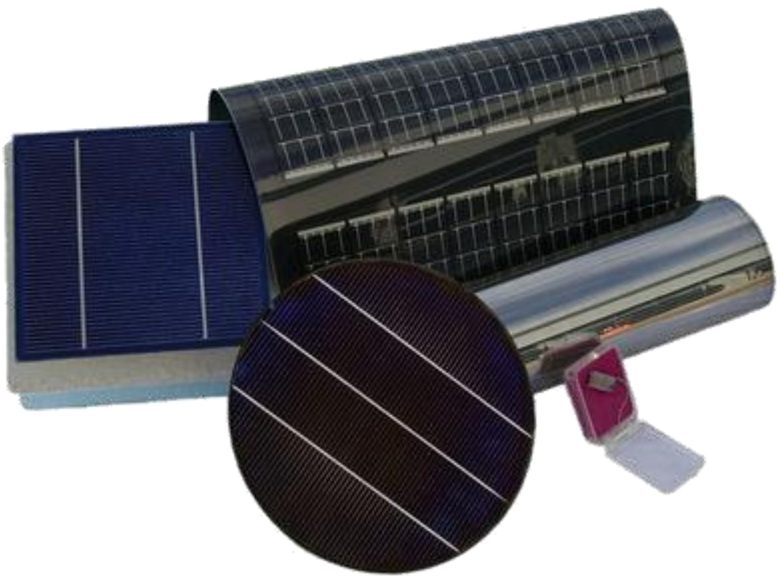
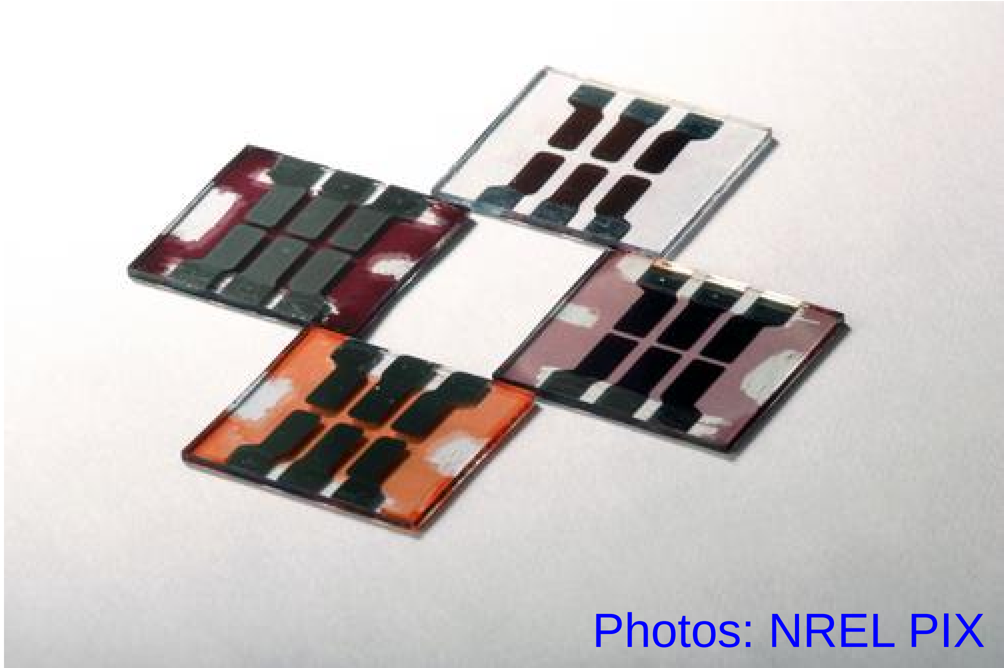
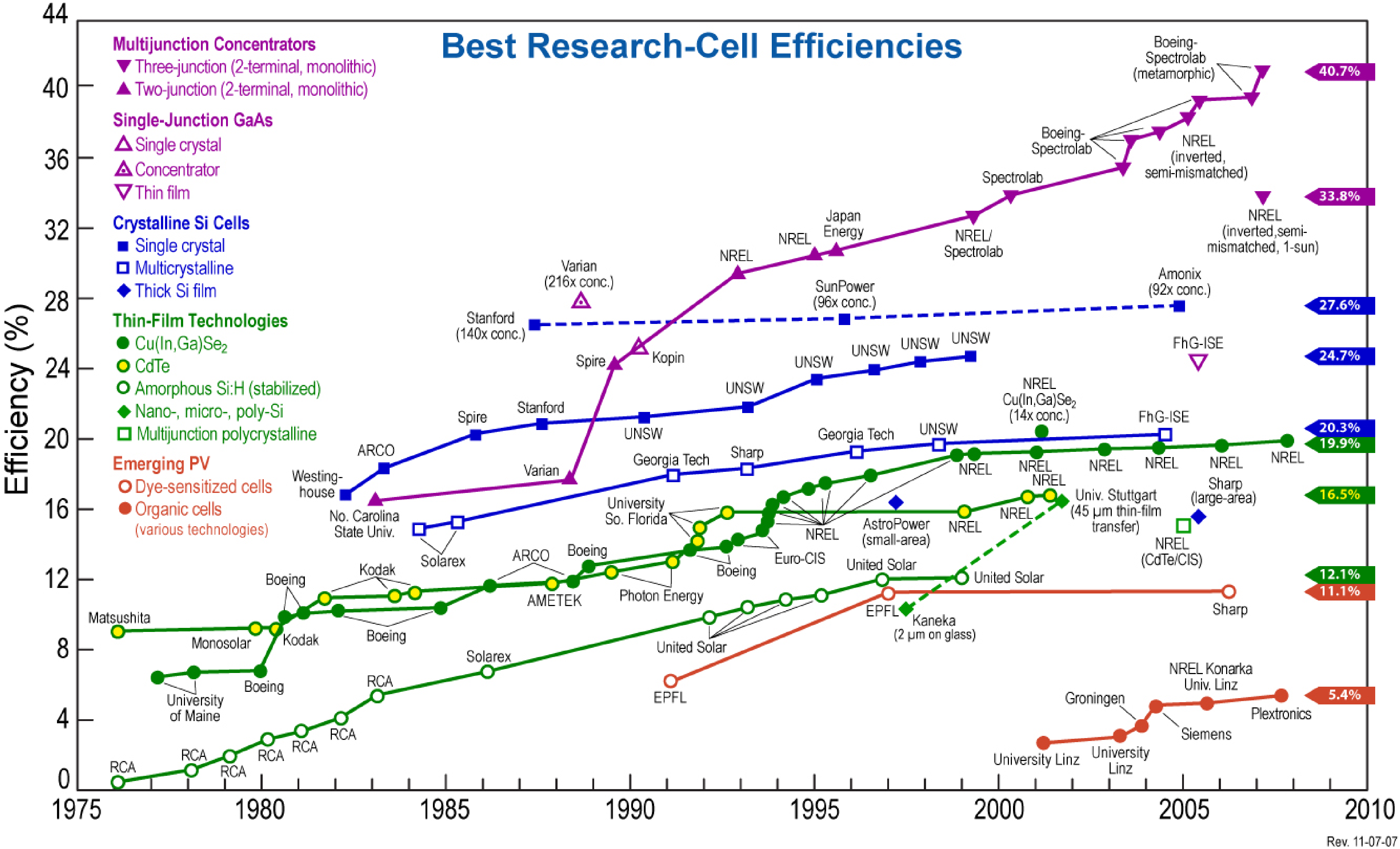
Solar Cell Technologies

- 1st Generation: Crystalline silicon
- 2nd Generation: amorphous silicon, CdTe, CIGS (thin film technologies)
- 3rd Generation: organic and dye sensitized





Photos: NREL PIX


Best Research-Cell Efficiencies
Efficiency (%)
Multijunction Concentrators
Three-junction (2-terminal, monolithic)
Two-junction (2-terminal, monolithic)
Single-Junction GaAs
Single crystal
Concentrator
Thin film
Crystalline Si Cells
Single crystal
Multicrystalline
Thick Si film
Thin-Film Technologies
Cu(In,Ga)Se2
CdTe
Amorphous Si:H (stabilized)
Nano-, micro-, poly-Si
Multijunction polycrystalline
Emerging PV
Dye-sensitized cells
Organic cells
(various technologies)
40.7%
33.8%
27.6%
24.7%
20.3%
19.9%
16.5%
12.1%
11.1%
5.4%
Rev. 11-07-07

Source: NREL

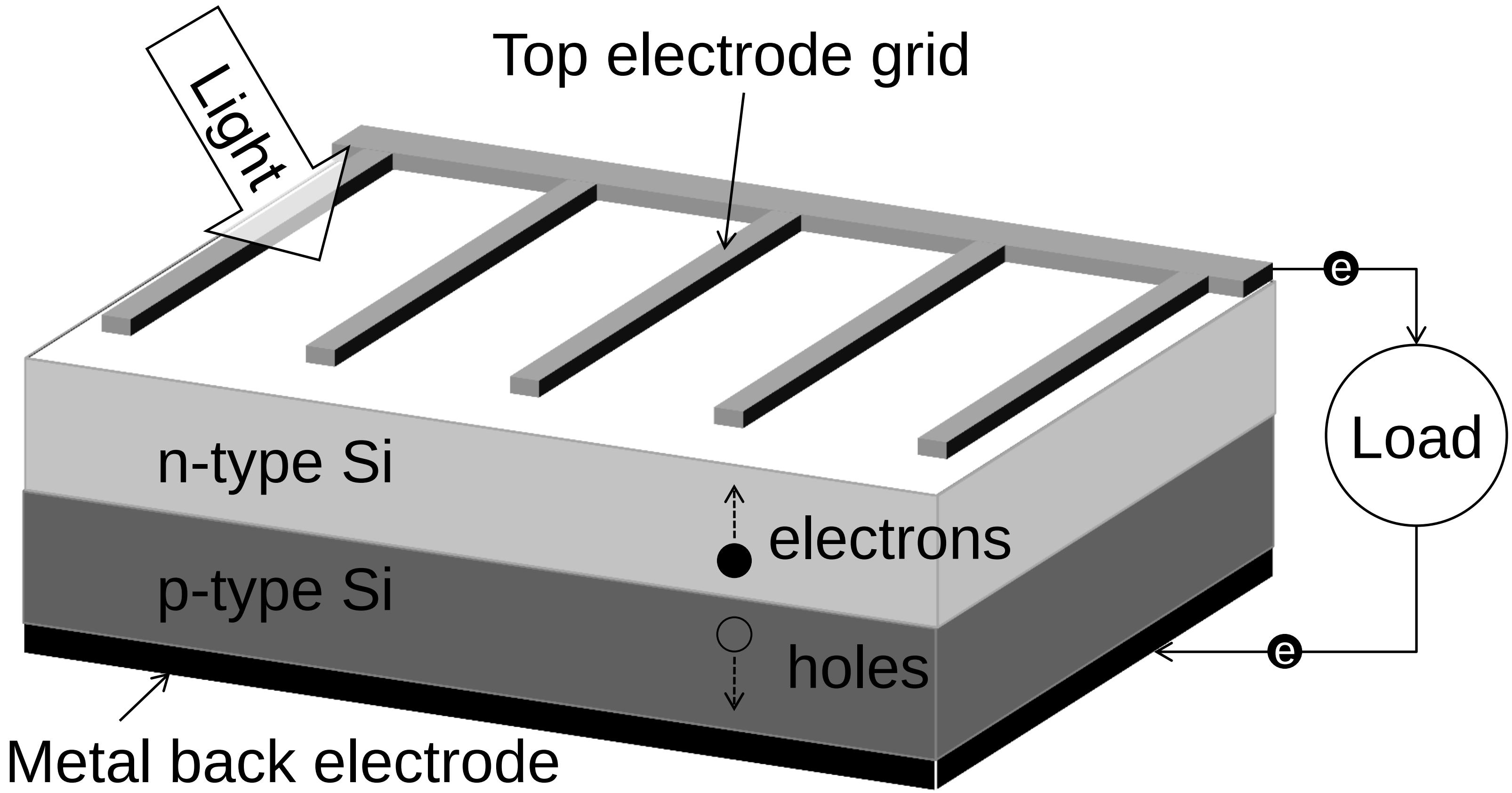
First Generation Solar Cell

- One p-n junction
- Made of very high purity silicon
- Can be single crystal or multicrystalline

Principle of Operation

1. Light absorption creates free charge carriers (electrons and holes)
2. The p-n junction directs current to flow in only one direction
3. Charge carriers are collected at the electrodes, which allow current to flow through an external circuit

First Generation Solar Cell



First Generation Solar Cell

Advantages

- High efficiency
- Long lifetime

Disadvantages

- Expensive materials
- Expensive production processes
- Rigid structures
- Fragile

The aim of organic solar cell research is to overcome the disadvantages by using less expensive materials and less expensive production processes.

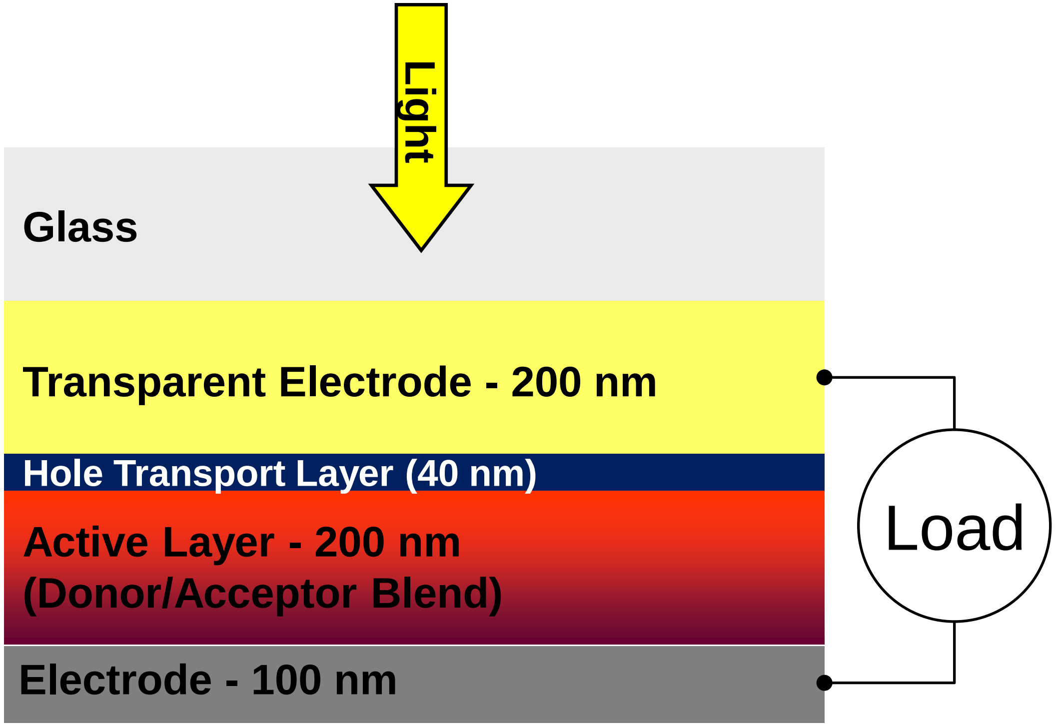
Organic Solar Cells

Organic solar cells are sometimes called plastic solar cells

Each device contains many layers

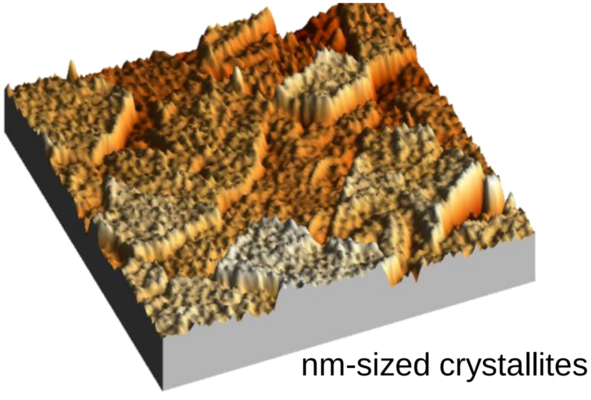
The active layer usually contains a mixture of two components: electron donor and electron acceptor

They are made up of materials such as: conductive polymers, small molecule semiconductors

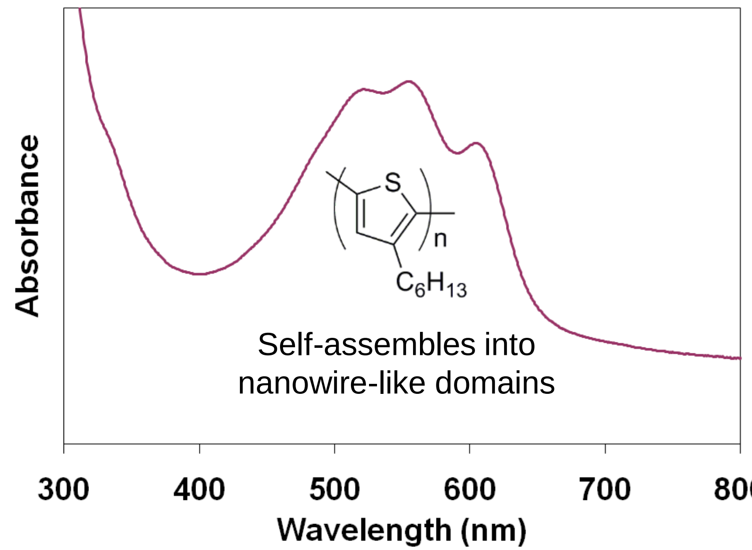


Organic Solar Cells: Materials

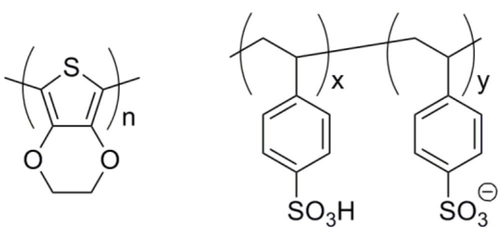
Transparent Electrode
Indium Tin Oxide (ITO)

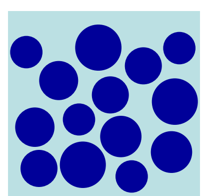


Active Layer Donor
Poly(3-hexylthiophene) (P3HT)



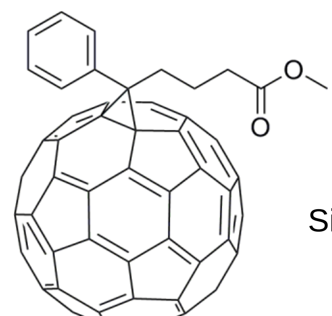
Hole Transport Layer
PEDOT:PSS





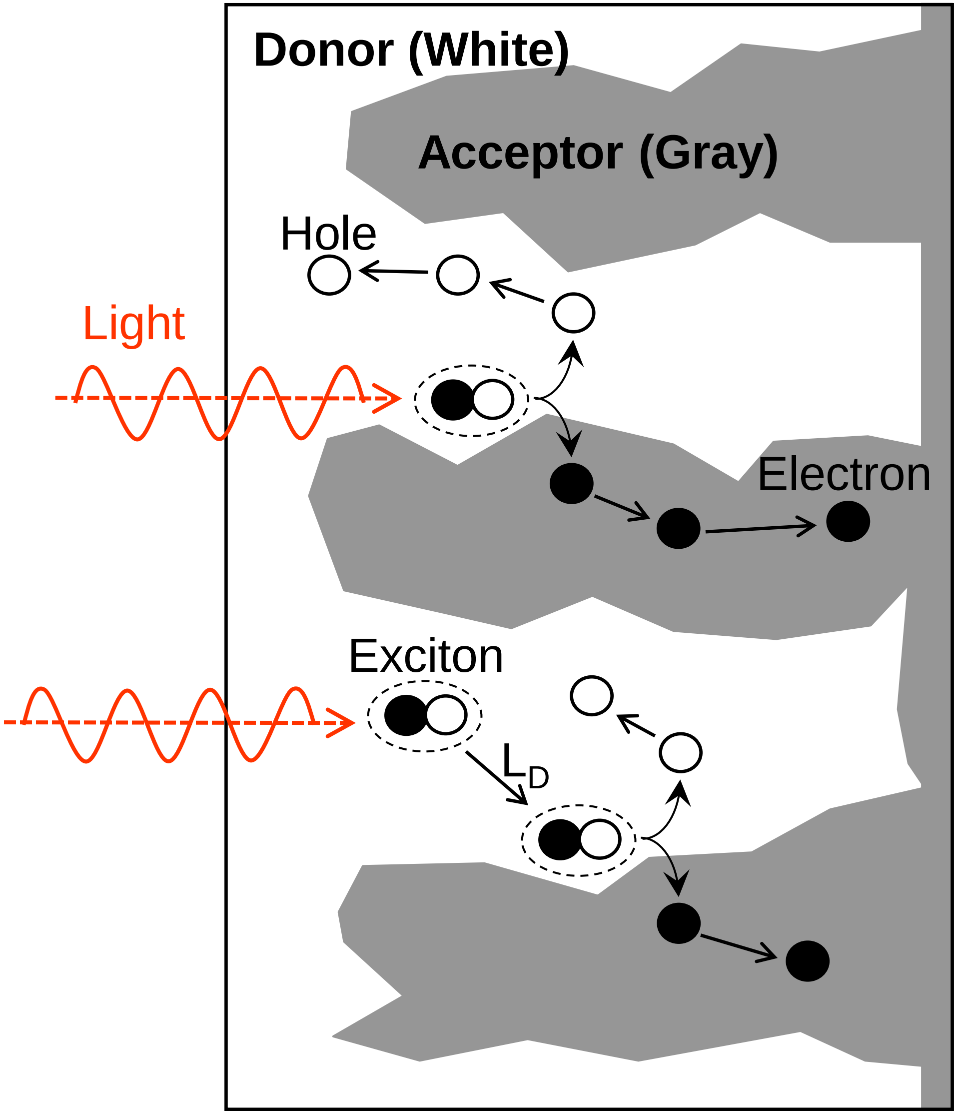
Aqueous colloidal suspension with 20-80 nm particles

Active Layer Acceptor
Fullerene Derivative (PCBM)



Size: 1-2 nm

Active Layer Morphology



Light absorption creates excited species called excitons

Excitons must dissociate at donor-acceptor interface in order to create free charge carriers

Excitons have a limited lifetime and a limited diffusion distance (L_D)

L_D is on the order of nanometers

Excitons are lost if they do not dissociate into free electrons and holes

Therefore, donor and acceptor materials must be organized into nanoscale domains

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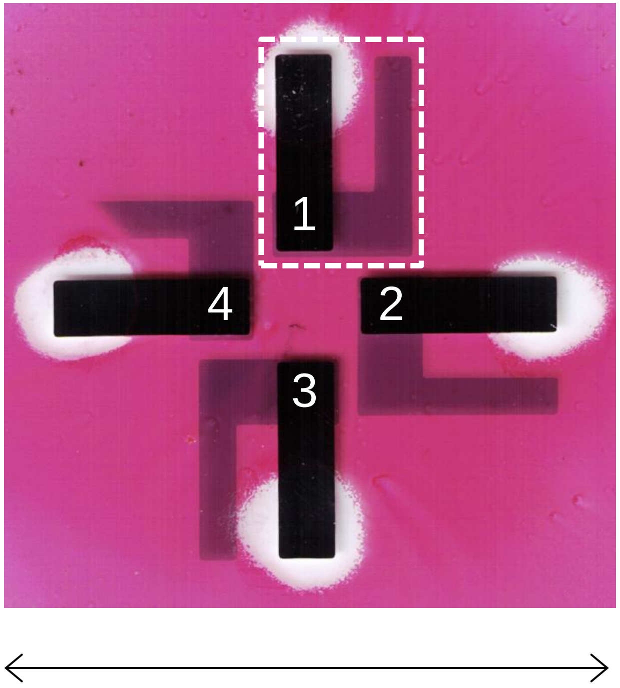
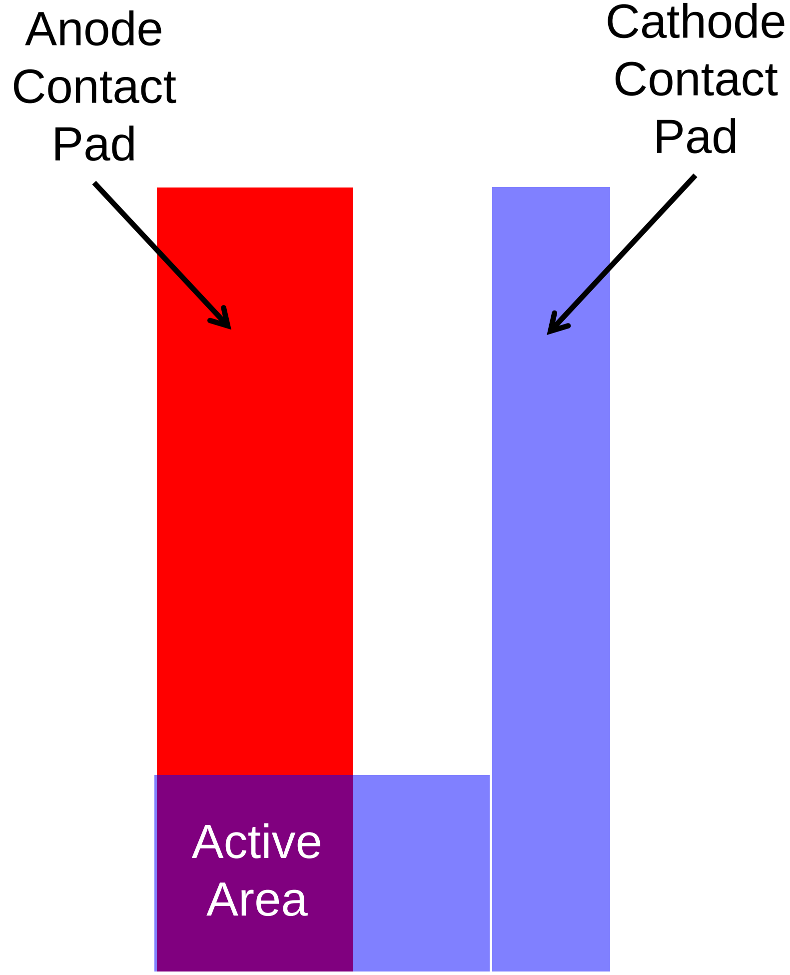
Processing of Lab-Scale Devices

- Typically, lab-scale organic solar cells are small in area (< 1 cm^2)
- Example: If a device is 3 mm x 3 mm, the active area is 9 mm^2 or 0.09 cm^2
- Small devices are easy to fabricate and handle in the lab.
- Many small devices can be made on one substrate (for optimization experiments).
- Active area is defined by where the anode and cathode overlap to make a complete sandwich structure.

Example of Device Layout

Example: 4 independent solar cells on one substrate



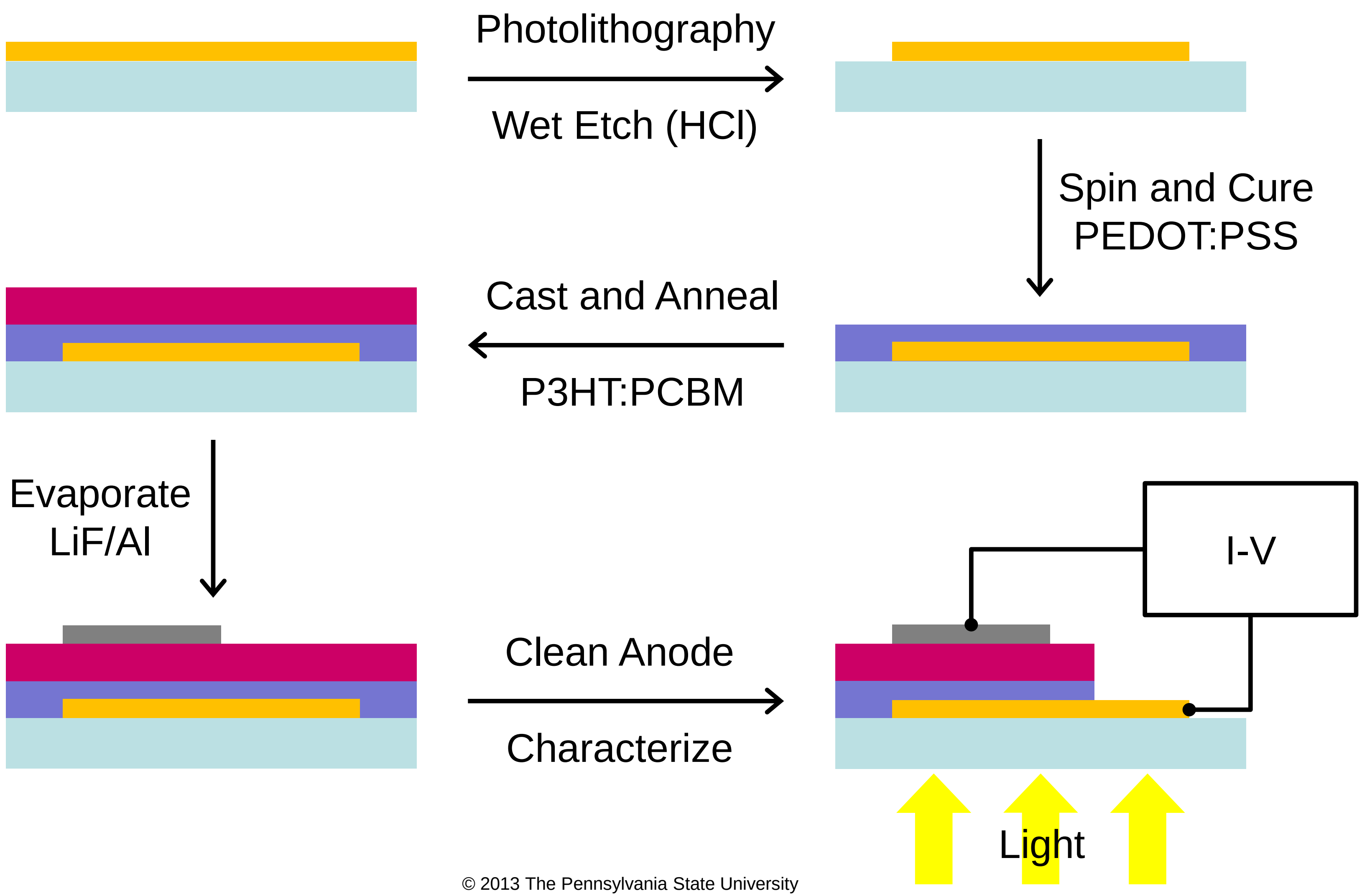


One Device (top view)

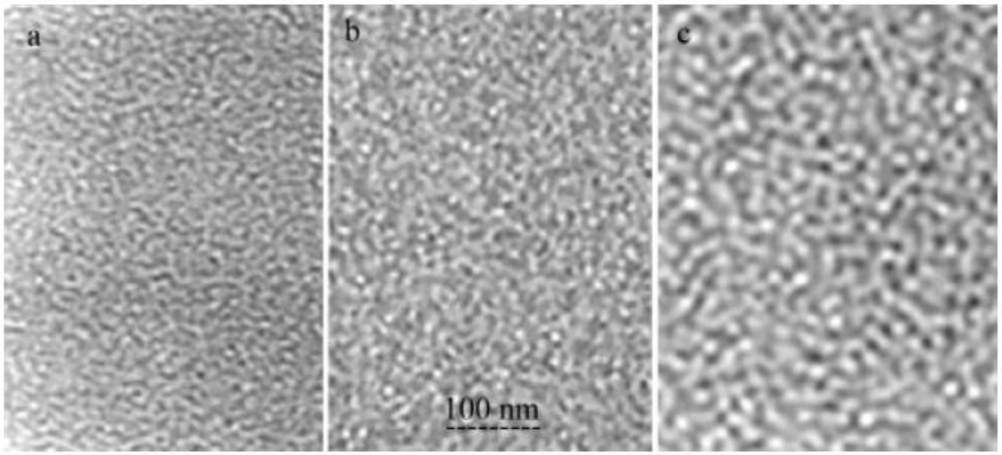
Processing Steps

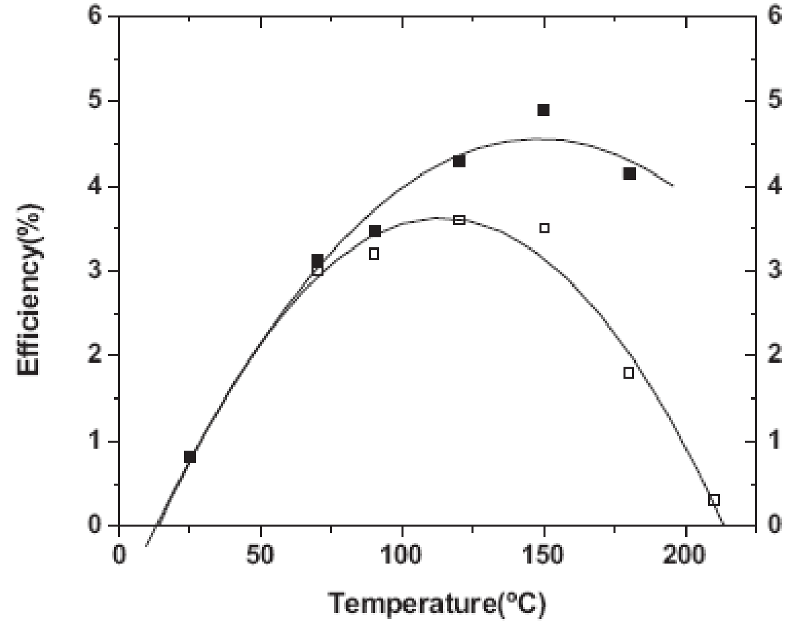
Step	Description
Pattern ITO	Photolithography and Wet Etch
Clean ITO	Oxygen Plasma or UV-Ozone
Cast PEDOT:PSS	Spin Coater
Cure PEDOT:PSS HTL	Oven or Hot Plate
Cast P3HT:PCBM Active Layer	Spin Coater
Thermal Annealing	On 150 C Hot Plate
Evaporate LiF/Al Cathode	Metal Evaporator
Clean Anode Contact	Q-tip and Toluene
I-V Characterization	Solar Simulator

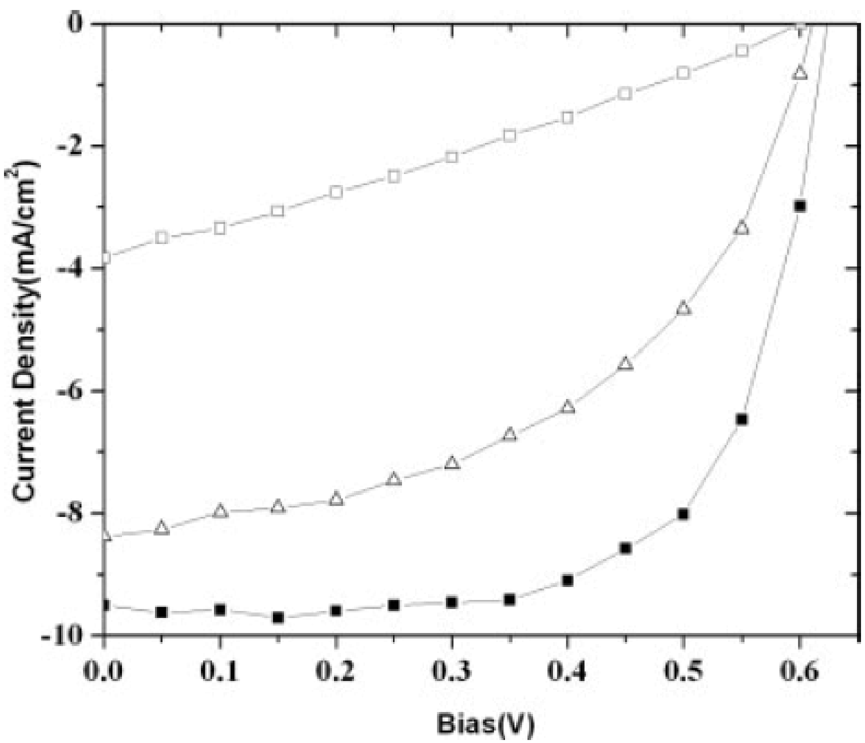
Processing Steps

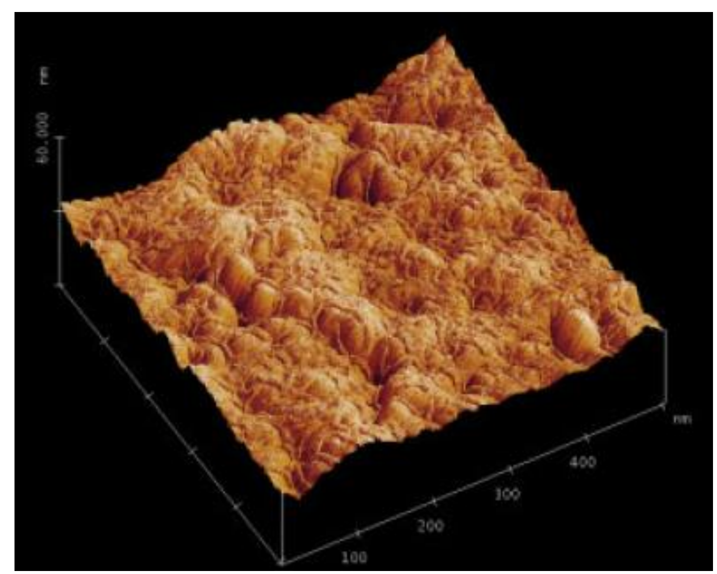


Thermal Annealing P3HT:PCBM









Adv. Funct. Mater. 2005, 15, 1617.

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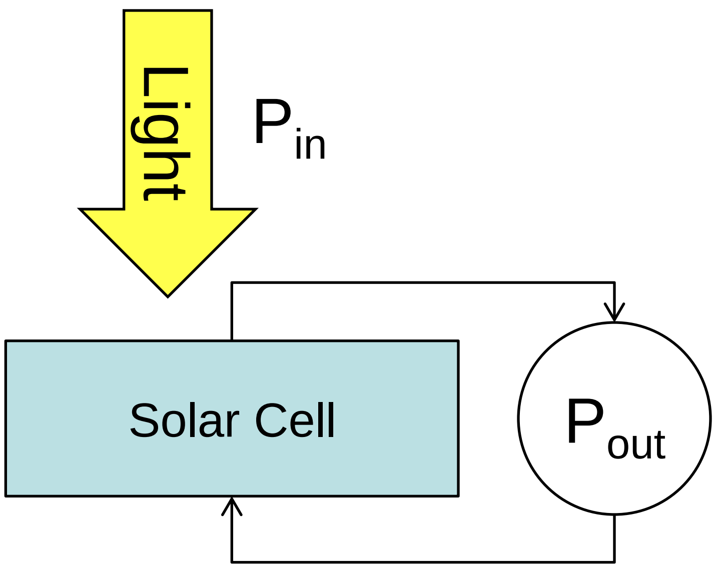
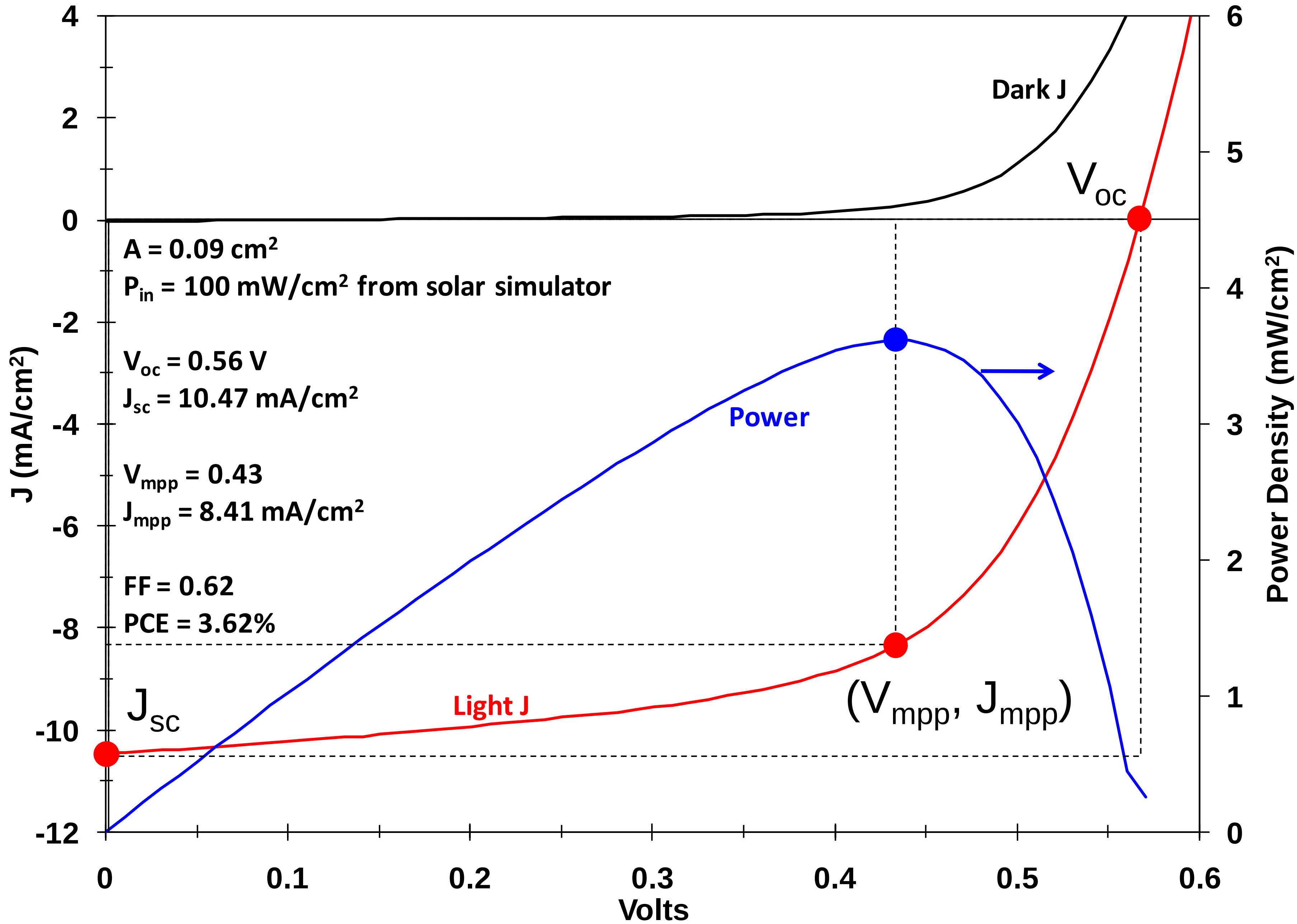
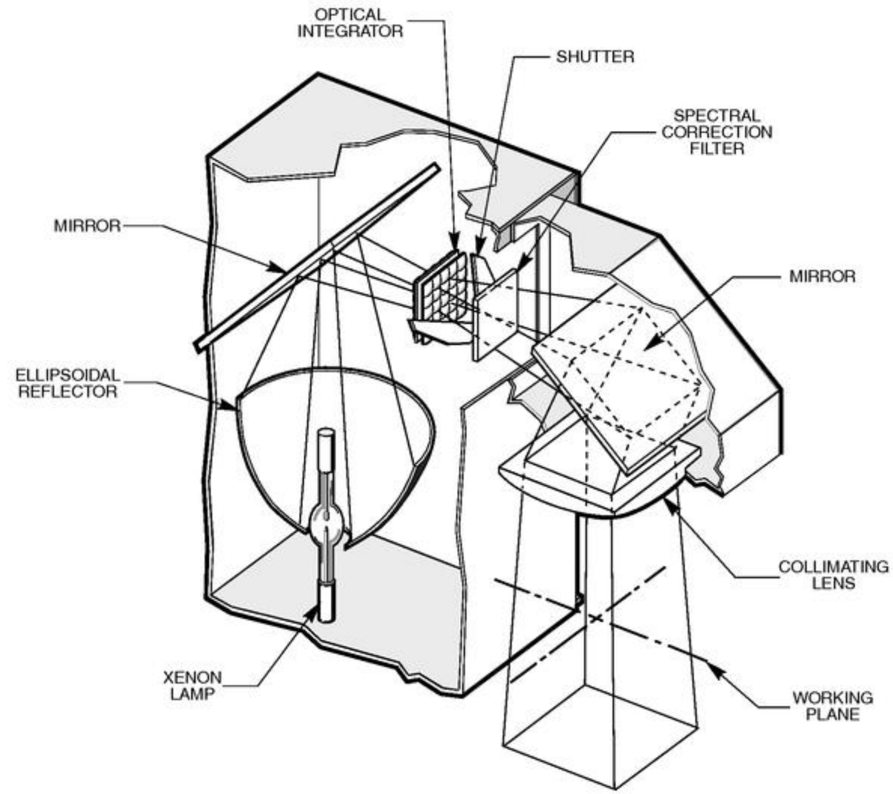




Dark J
Voc
A = 0.09 cm2
Pin = 100 mW/cm2 from solar simulator
Voc = 0.56 V
Jsc = 10.47 mA/cm2
Vmpp = 0.43
Jmpp = 8.41 mA/cm2
FF = 0.62
PCE = 3.62%
Power
Light J
Jsc
(Vmpp, Jmpp)
J (mA/cm2)
Power Density (mW/cm2)
Volts
4
2
0
-2
-4
-6
-8
-10
-12
0
0.1
0.2
0.3
0.4
0.5
0.6
6
5
4
3
2
1
0

Solar Simulators



- Xenon arc lamp with filters to approximate AM1.5
- Spectral mis-match factors
- Calibration of light intensity (P_{in})
- Temperature control of the sample

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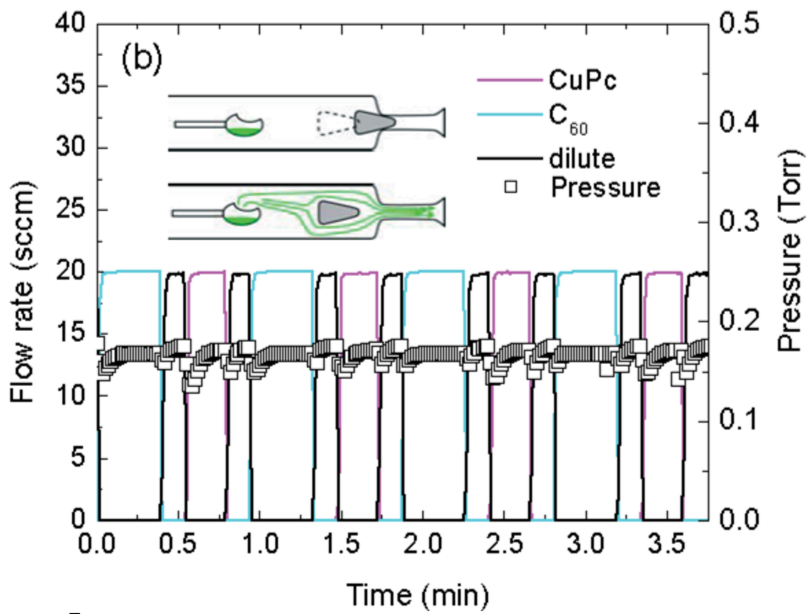
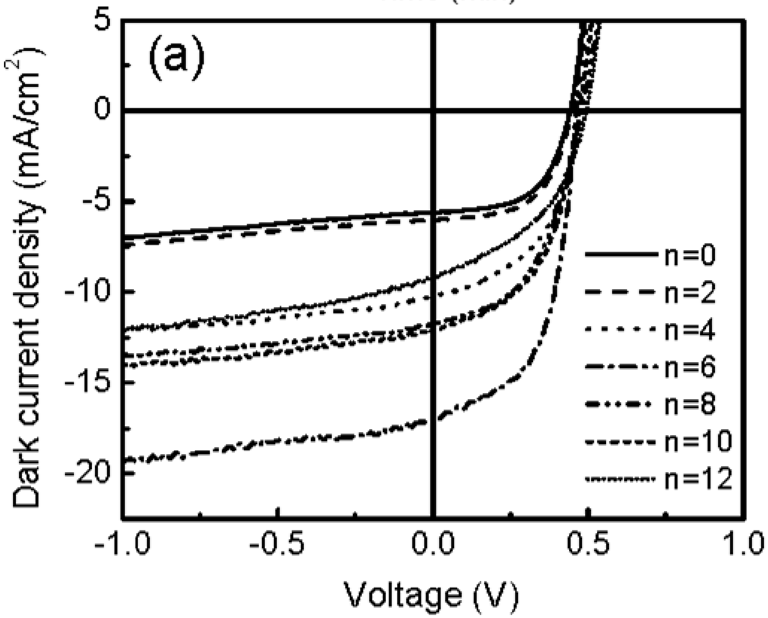
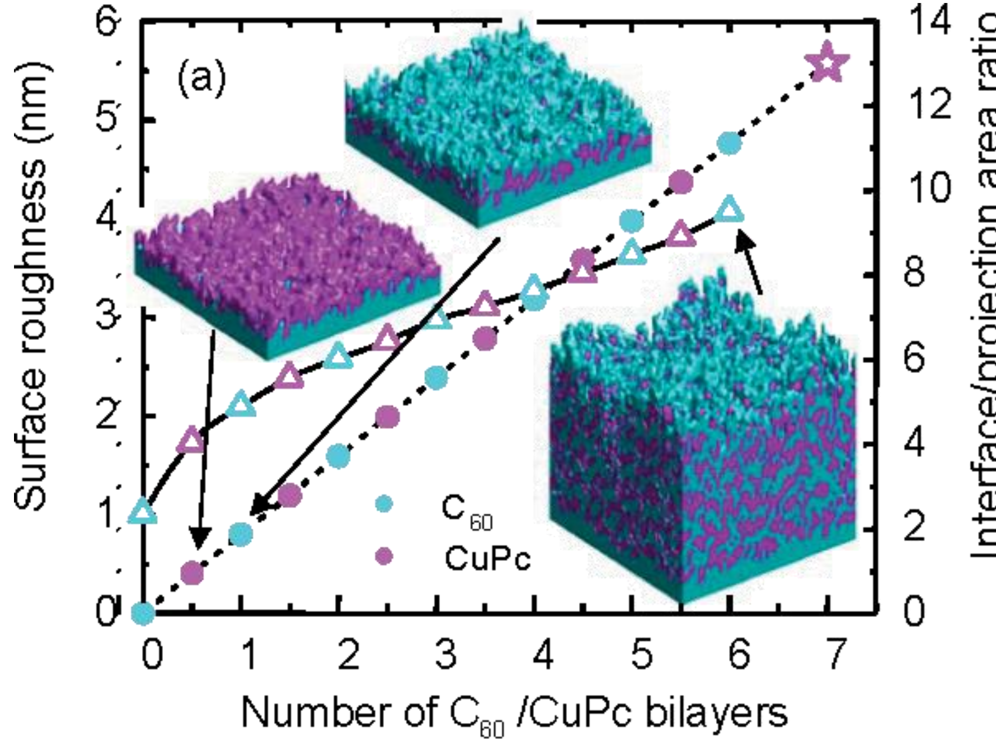
Alternative Processing Techniques

- Roll-to-roll printing
- Ink-jet printing
- Screen printing
- Doctor blading
- Vacuum-based deposition

Controlled Structuring of Small Molecules







Growth of $[C_{60}(3\ nm)/CuPc(3\ nm)]_n$ nanocrystalline donor/acceptor (DA) networks. n = number of bilayers.

Advanced Materials 2007, 19, 4166.

Organic Solar Cells

Advantages

- Materials are amenable to low-cost processing
- Polymeric materials can be tailored to meet specifications (e.g., band gap, solubility)

Disadvantages

- Less efficient (so far) than other technologies
- Long term stability needs to be proven
- Viewed as cutting edge, but risky, technology

Conclusions

- Solving issues related to energy production, storage, and distribution will take a concerted effort.
- Plenty of challenges for all areas of science and technology.
- Nanotechnology is poised to make major contributions to the energy sector.
- Organic solar cells show promise for low-cost production ($/Watt).