Solar Cells

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Why solar cells are likely to provide a significant fraction of our power

- We need ~ 30 TW of power, the sun gives us 120,000 TW.

- Solar cells are safe and have few non-desirable environmental impacts.

- The sun shines when we need energy the most.

- Using solar cells instead of burning coal to generate electricity is a much easier way to reduce carbon emissions than replacing gasoline in vehicles.

Area needed to power the country

$(150\ \mathrm{km})^2$ of Nevada covered with 15 % efficient solar cells could provide the whole country with electricity

J.A. Turner, *Science* **285** 1999, p. 687.

Multicrystalline silicon solar cells: today's most popular technology

12 % efficiency
$420/m²

	Cost ($/W)
Cell	$2.50
Making the module	$1.00
Inverter	$0.50
Retro fit installation	$4-5.00
TOTAL	$8-9.00

Average cost over 30 yrs of PV cell electricity in CA including 6 % interest payments:	$0.34/kW-hr	actually lower if the interest is deducted from taxes
Average grid electricity in CA: Peak rates in CA:	$0.13/kW-hr $0.29/kW-hr	will rise over 30 years

Implications

• Solar cells are on the verge of being economically competitive when storage is not required. The market is growing at over 32 %/yr.

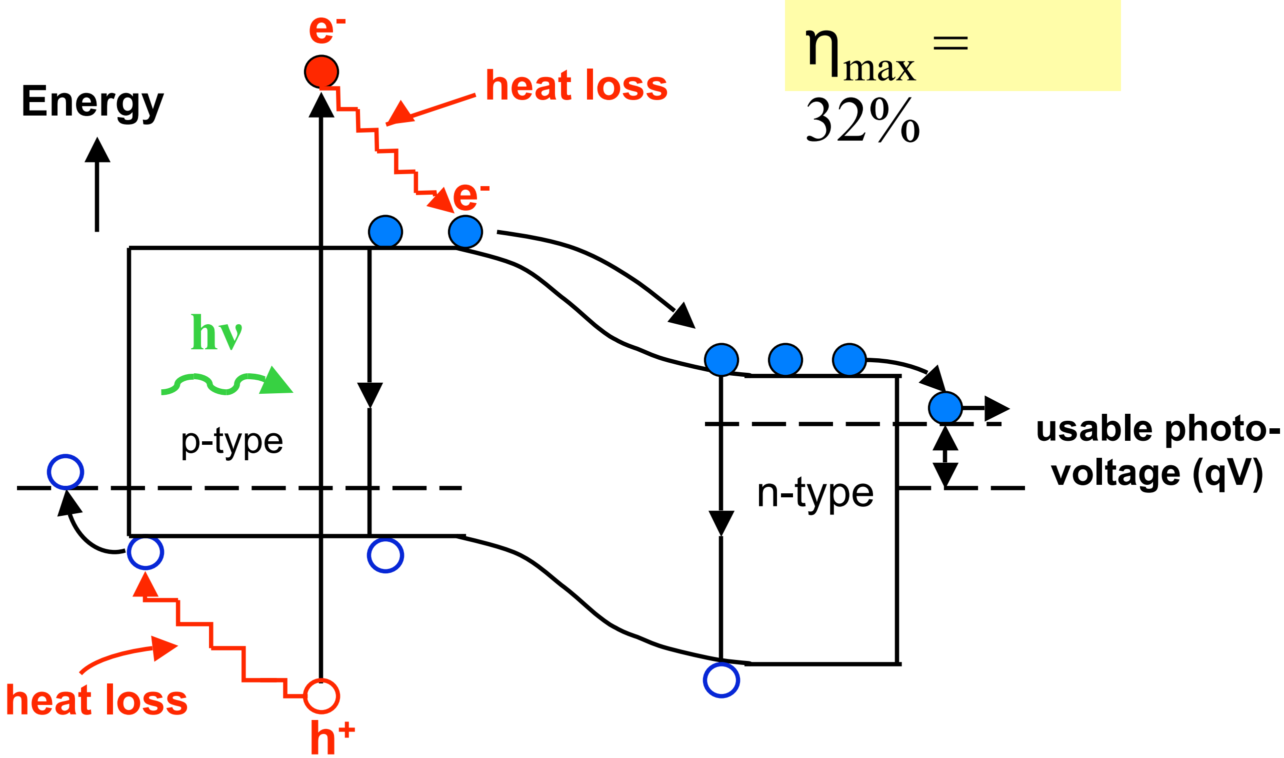
• Because a 40 % rebate is available, the demand currently exceeds the supply.

• Venture capitalists invested over $750 million in solar last year.

• A 3x cost reduction would lead to huge market growth.

• A 5-10x cost reduction coupled with batteries or electrolyzers would transform the entire way we obtain energy.

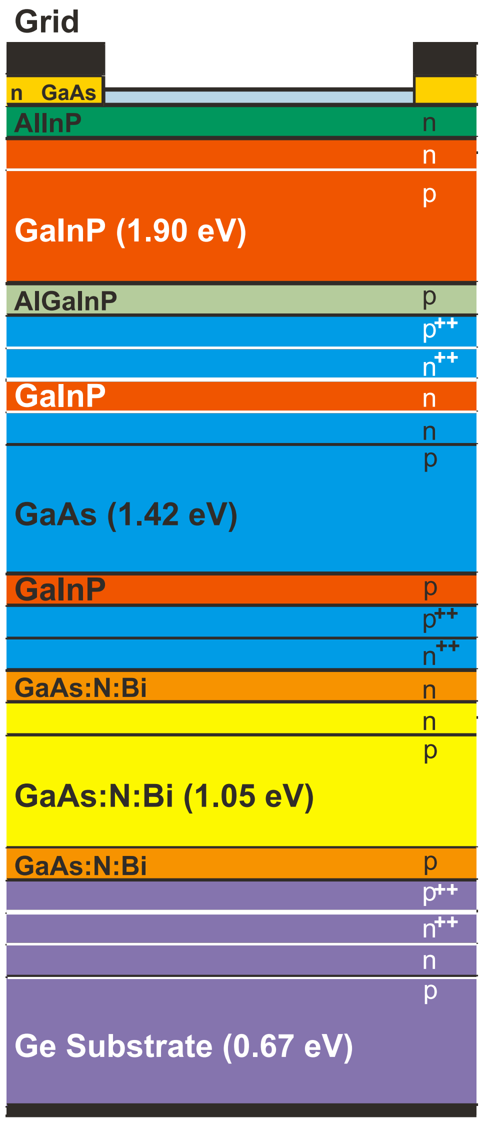
Conventional p-n junction photovoltaic (solar) cell



η_{max} = 32%

Jenny Nelson, *The Physics of Solar Cells*, 2003.

Multijunction cells



SpectroLab has achieved 37 % efficiency

Costs are estimated at $50,000/m², so concentrators must be used.

The cheapest option

Efficiency: 0.3 %

We don't have the land and water to provide the world with energy this way.

Can we artificially improve the efficiency?

Traditional Thin Film Solar Cells

A thin film of semiconductor is deposited by low cost methods.

Less material is used.

Cells can be flexible and integrated directly into roofing material.

CIGS (CuInGaSe_2)
World record: 19.5 %
Stable
Is there enough In in the world?

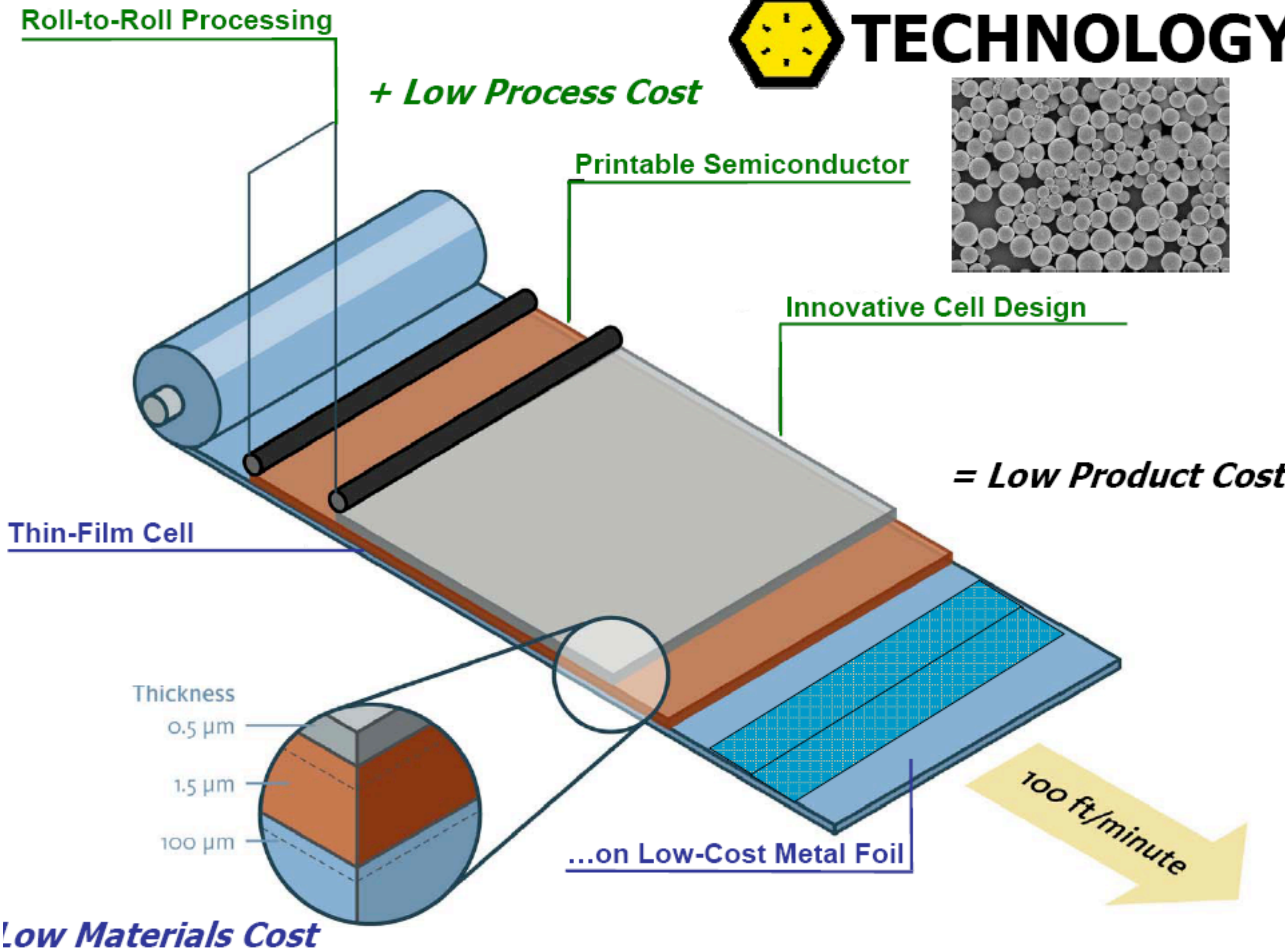
amorphous Si
World record: 12.1 %
not completely stable

CdTe
World record: 16.5 %
Stable
Cd is toxic

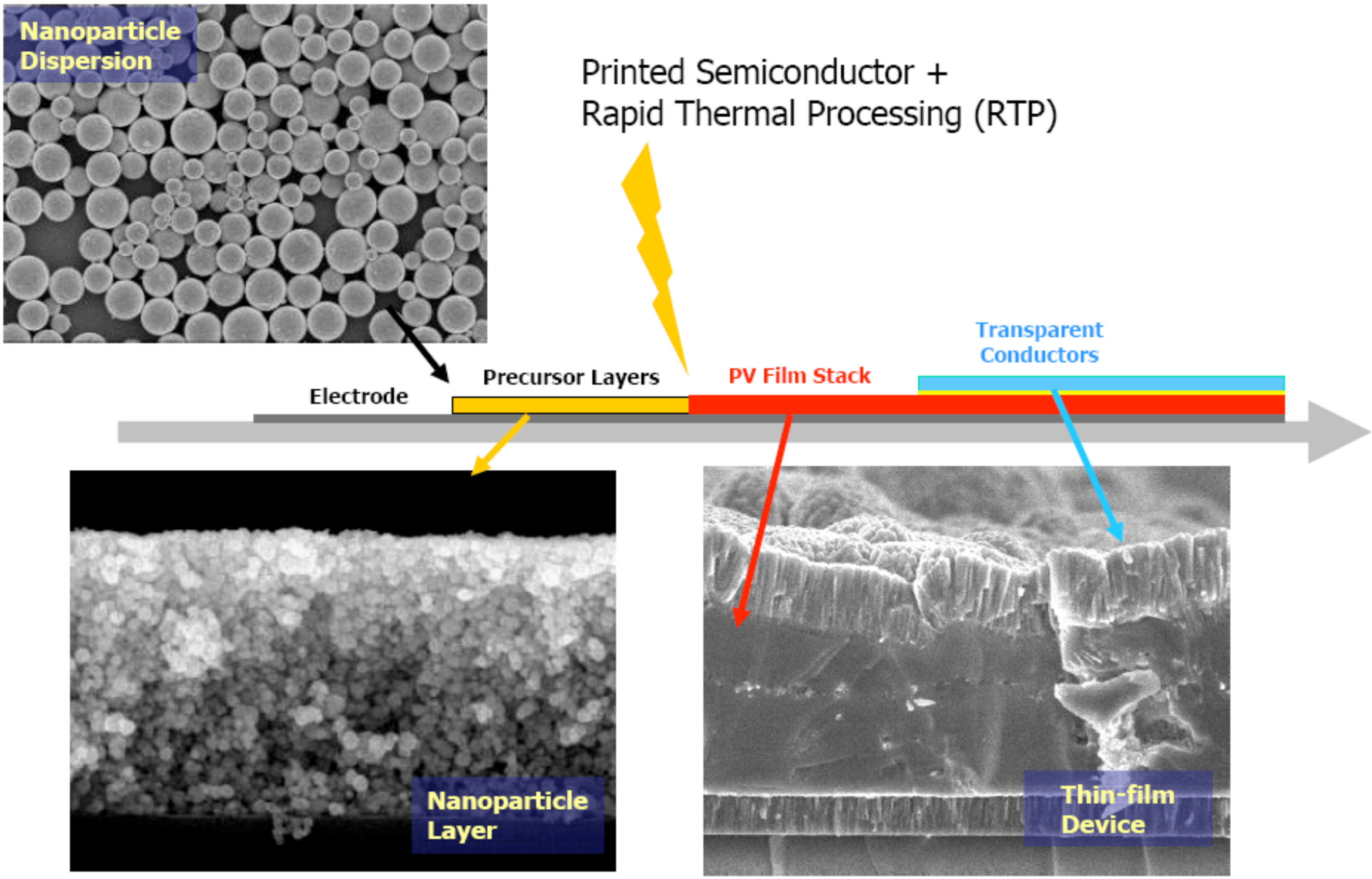
Nanosolar

“A New Day Dawning? Silicon Valley Sunrise,” *Nature* **443**, September 7, 2006, p. 19.

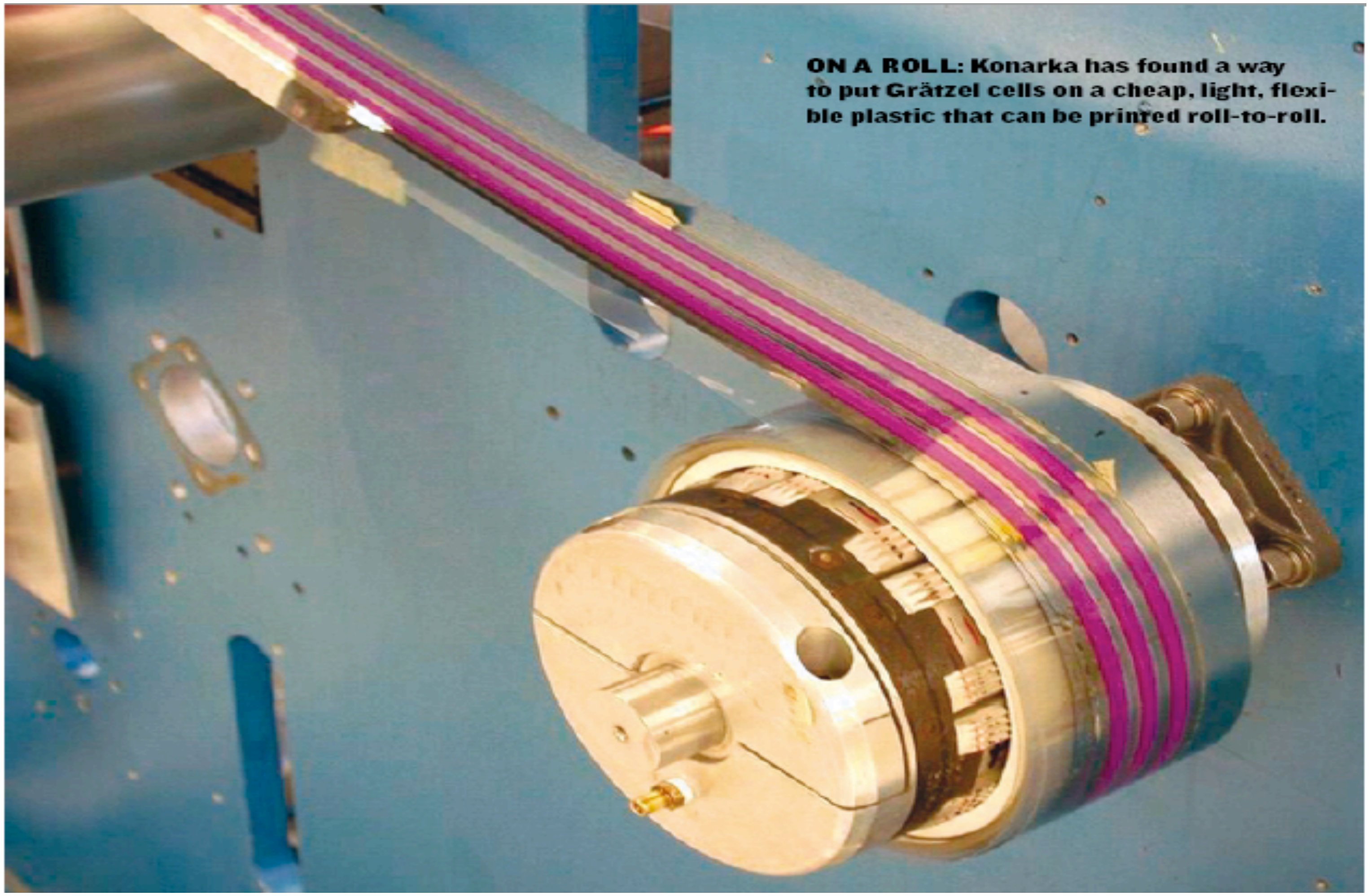
TECHNOLOGY


Roll-to-Roll Processing
+ Low Process Cost
Printable Semiconductor
Innovative Cell Design
= Low Product Cost
Thin-Film Cell
Thickness
0.5 µm
1.5 µm
100 µm
...on Low-Cost Metal Foil
100 ft/minute
Low Materials Cost

PRINTED SEMICONDUCTOR



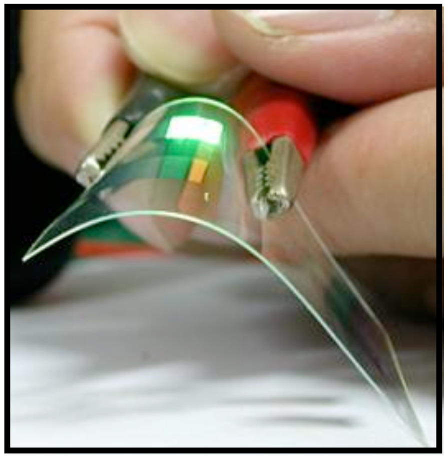
Roll-to-Roll coating: A route to taking the costs below $\$50/m^2$ and keeping efficiency > 10 %.



P. Fairley, *IEEE Spectrum.* Jan. 2004 p.28

A New Generation of Low-Cost Organic Electronics

Organic LED Displays

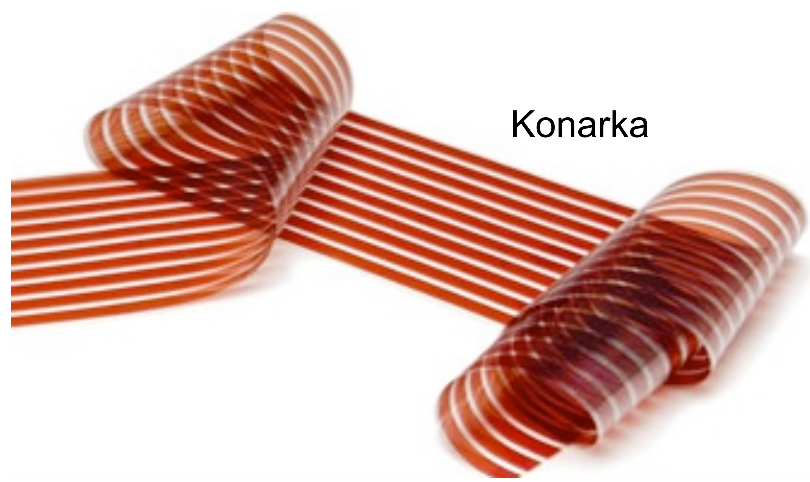


Organic LED Lighting

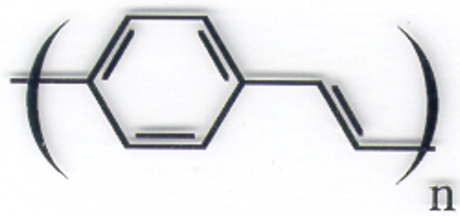
Electronic Paper w/ polymer backplane

Polymer Vision’s Readius

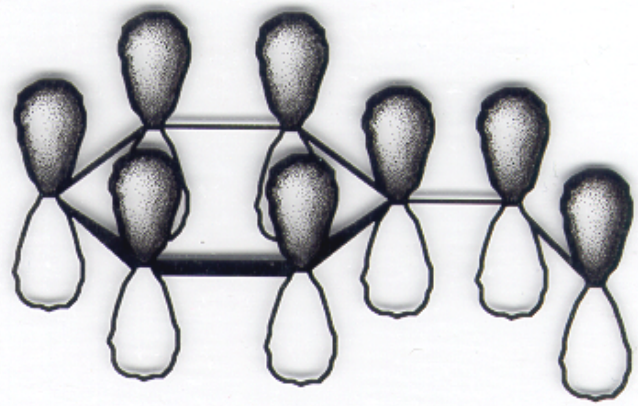
Organic Solar Cells



Conjugated polymers

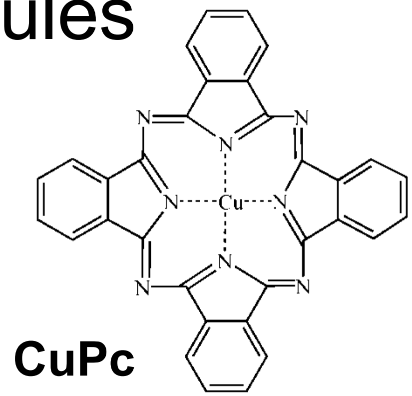


PPV



Conjugated (semiconducting) molecules

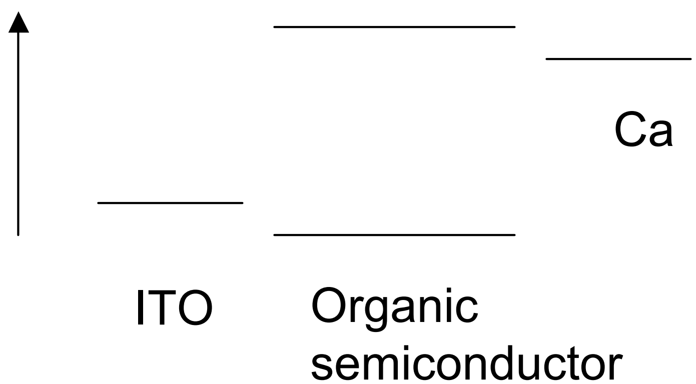
Abundant: > 70,000 tons/year
Non-toxic
Low-cost: ~1\$/g → 17¢/m^2
Stable

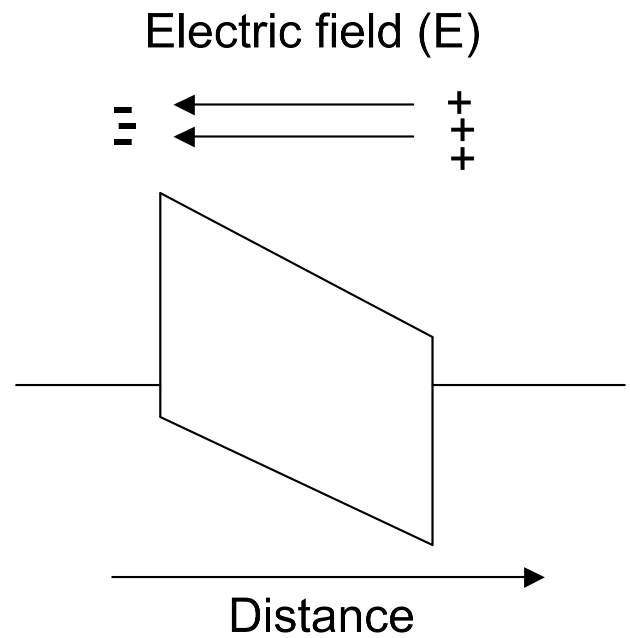


CuPc

Peter Peumans (Stanford Electrical Engineering)

Single semiconductor organic PV cells

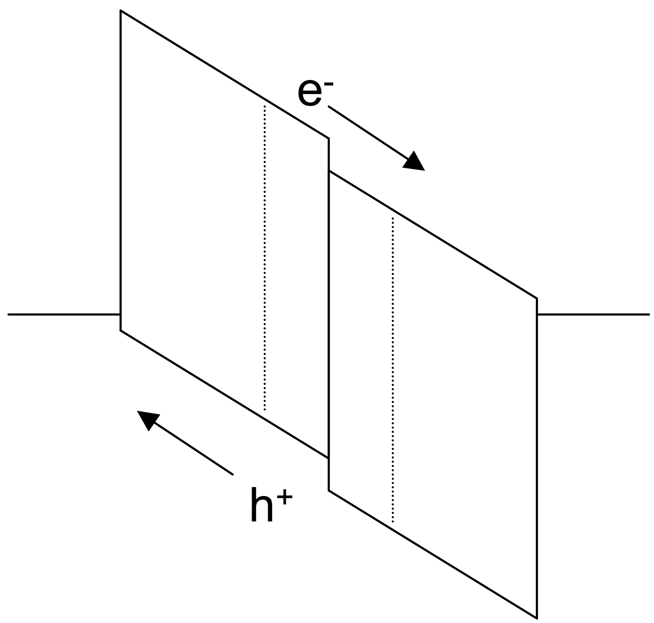




High exciton binding energy
Low mobility

Quantum efficiency < 1 %

Flat bilayer organic PV cells



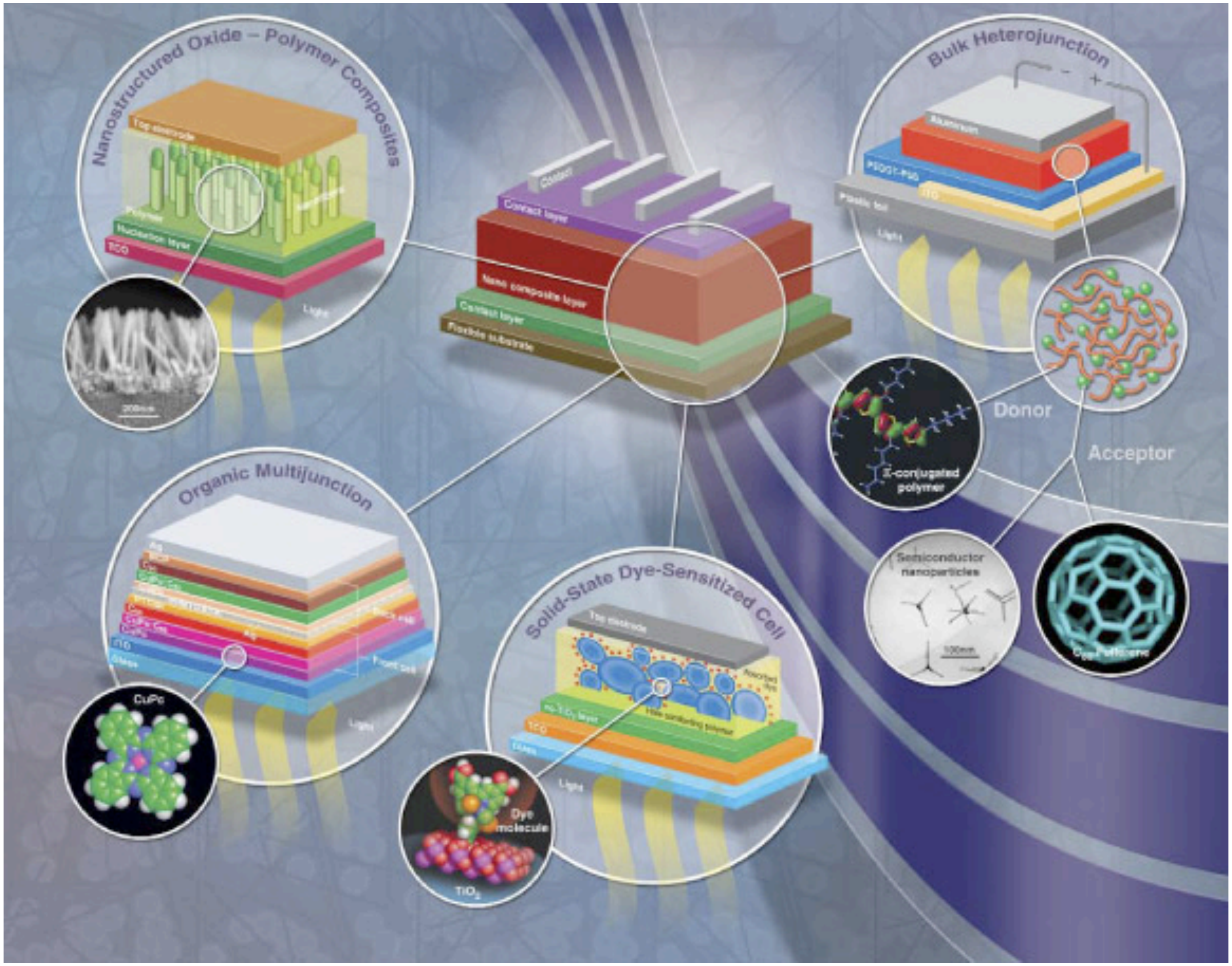
• Carriers are split at the interface.[1]

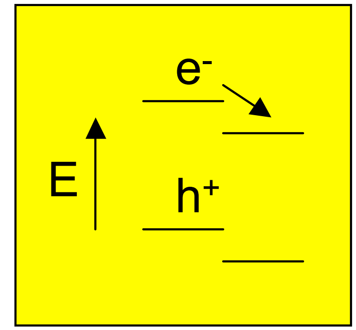
• They selectively diffuse to the electrodes.[2]

• Exciton diffusion length ~ 4-20 nm
• Absorption length ~ 100-200 nm

[1] C.W. Tang, *APL* **48** (1986) p. 183.
[2] B.A. Gregg, *J. Phys. Chem. B* **107** (2003) p. 4688.

Nanostructured Cells



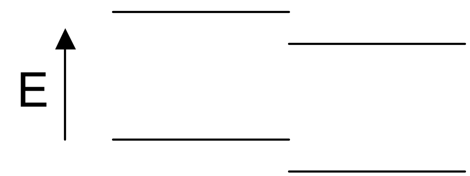


Excitons are split at interfaces.

Separating the electrons and holes enables the use of low quality materials

January 2005 *Materials Research Society Bulletin*

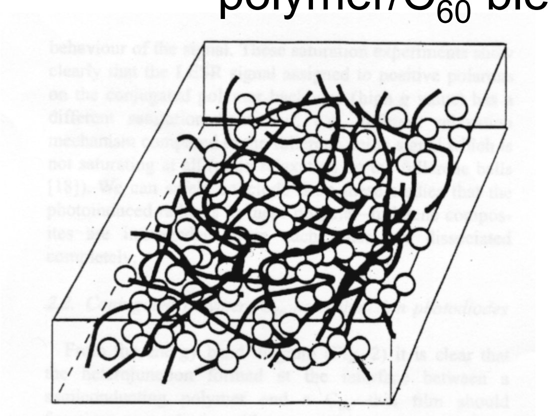
Bulk heterojunction PV cells made by casting blends



Polymer Electron acceptor

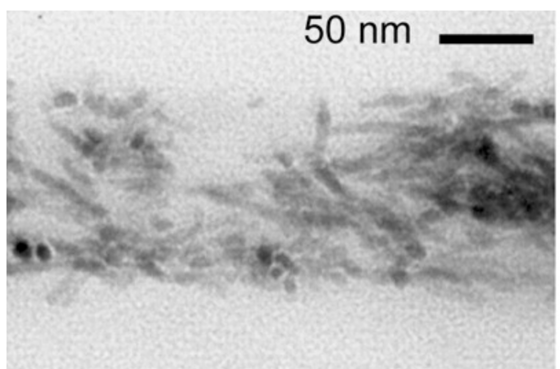
absorber	electron acceptor		Energy conversion efficiency (AM 1.5)
Polymer	C_{60} derivative	Plextronics	5.4 %
Polymer	polymer	Friend	1.9 %
Polymer	CdSe nanorods	Alivisatos	1.7 %
Polymer	ZnO nanocrystal	Janssen	1.6 %

polymer/C_{60} blend



Heeger et al. *Science* **270** (1995) p. 1789.

polymer/nanorod blend



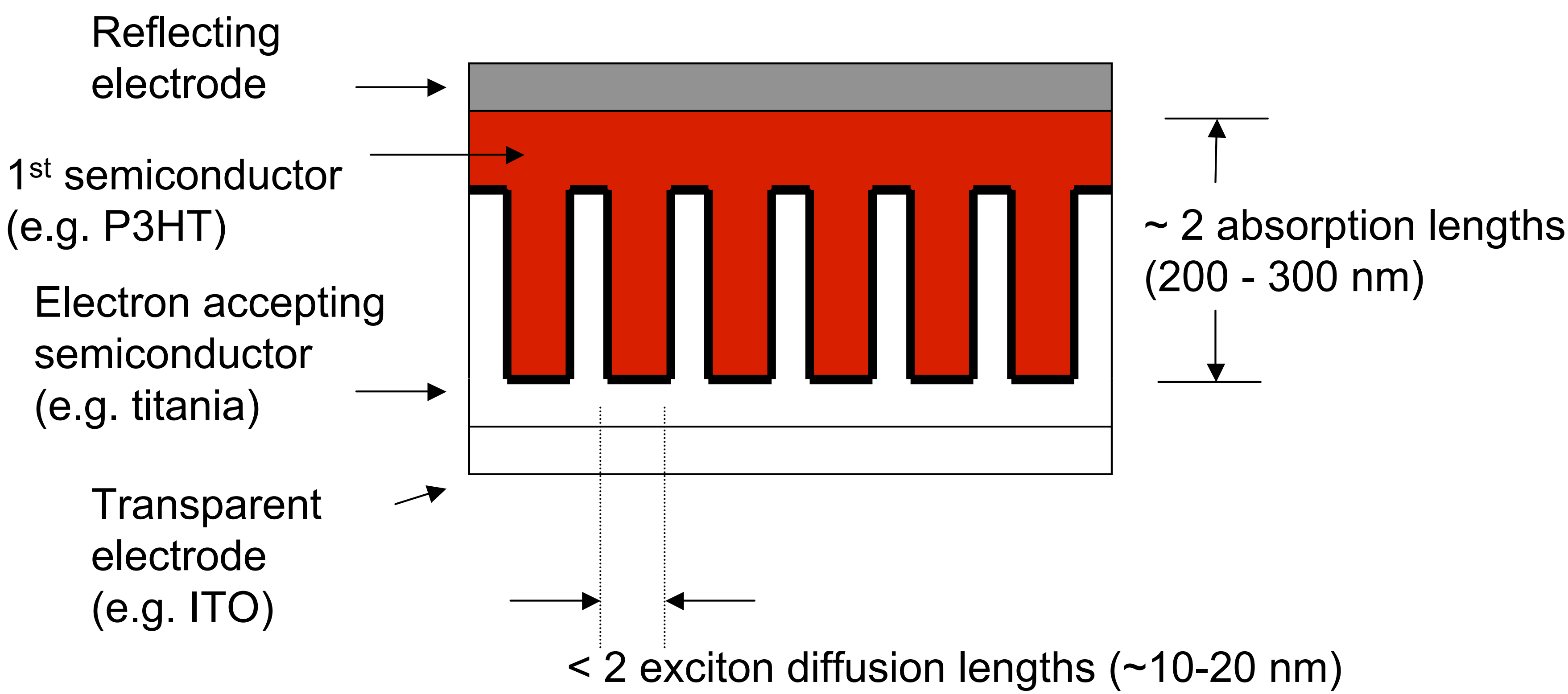
Alivisatos et al., *Science* **295** (2002) p. 2425

☺ fabrication is simple

☹ not all excitons reach at interface

☹ there are deadends

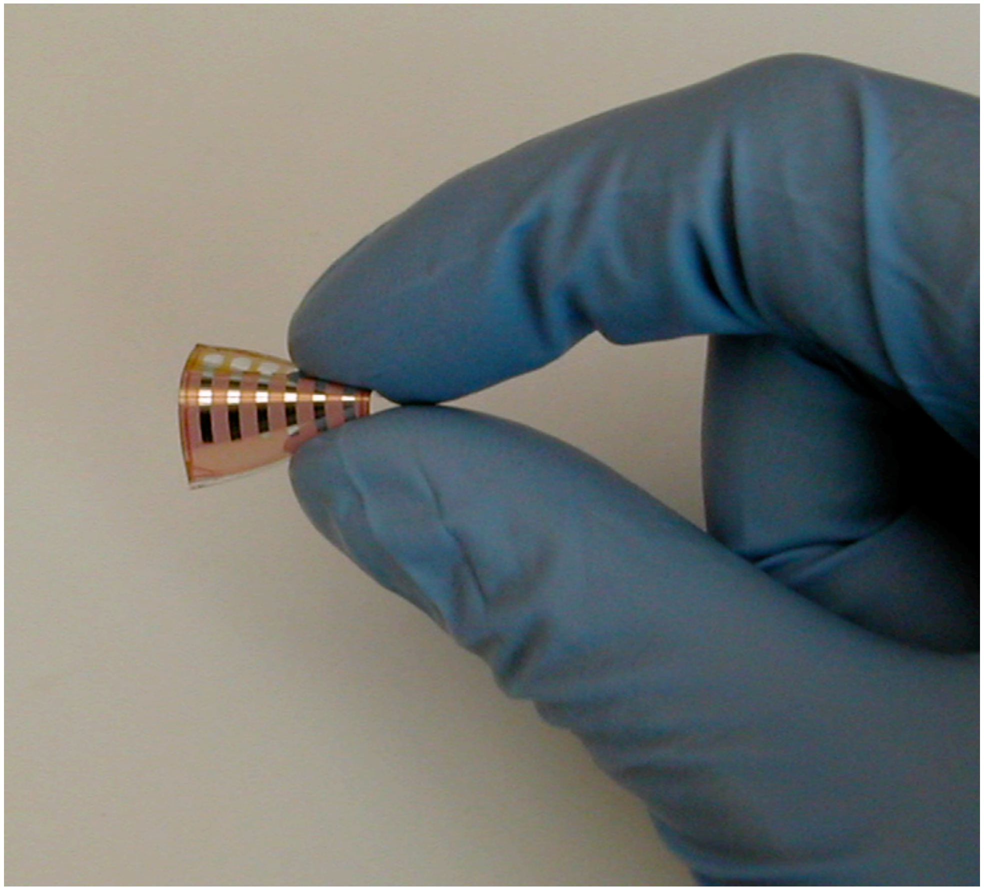
Ordered bulk heterojunctions



- Almost all excitons can be split
- No deadends
- Polymer chains can be aligned

- Easy to model
- Semiconductors can be changed without changing the geometry.

CNT's can be deposited from solution and are more flexible



CNT-Film on PET Devices

Bending cells to 5mm curvature had no effect

Bending cells to 1mm reduced efficiency by 20%, but not irreparably.

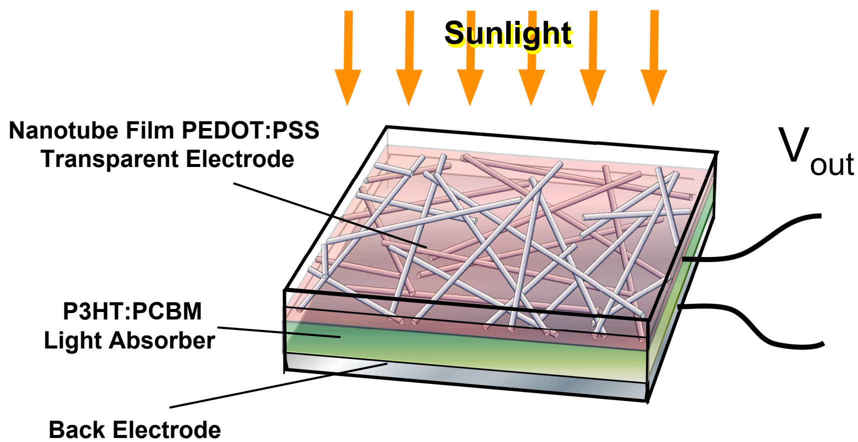
ITO on PET Devices

Bending cells to 5mm destroyed cells irreversibly.

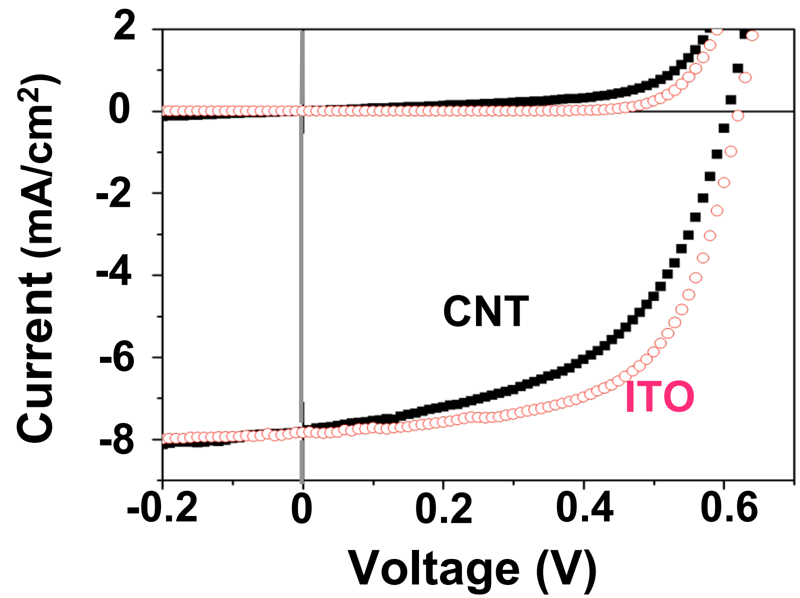
Mike Rowell, M. Topinka, M.D. McGehee, Prall, Dennler, Sariciftci, Hu, Gruner, APL, 88 (2006) p. 233506.

Replacing ITO electrodes with carbon nanotube meshes

CNT-TC Solar cell Schematic



Solar cell I-V



	Efficiency	j_{sc}	V_{oc}	Fill Factor
CNT cell	2.5%	7.8 mA/cm²	605 mV	0.42
ITO cell	3.0%	8.0 mA/cm²	610 mV	0.52

in collaboration with George Gruner, L.Hu, D.Hecht, (UCLA)