Hot Science Cool Talks

UT Environmental Science Institute

69

Powered Paint: Nanotech Solar Ink

Dr. Brian Korgel

December 3, 2010

Powered Paint: Nanotech Solar Ink

Brian A. Korgel

Department of Chemical Engineering, Texas Materials Institute,
Center for Nano- and Molecular Science and Technology
The University of Texas at Austin
korgel@che.utexas.edu

December 3, 2010

To Lower the Cost of Solar Energy…

To Lower the Cost of Solar Energy…

Change the way solar cells are made

Slow, high temperature vacuum processes

To Lower the Cost of Solar Energy…

Change the way solar cells are made

Slow, high temperature vacuum processes

Print like newspaper

To Lower the Cost of Solar Energy…

Change the way solar cells are made

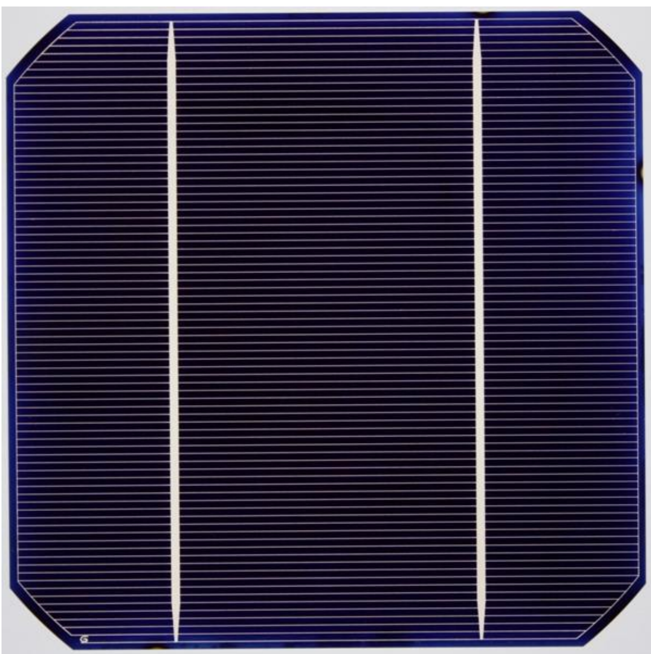
Slow, high temperature vacuum processes

Print like newspaper

Photovoltaic Paints…?

To Lower the Cost of Solar Energy…

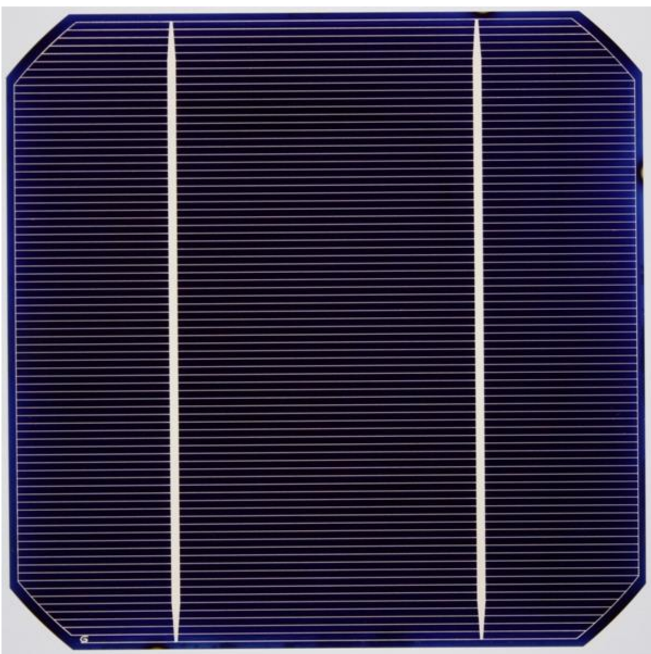
Change the way solar cells are made



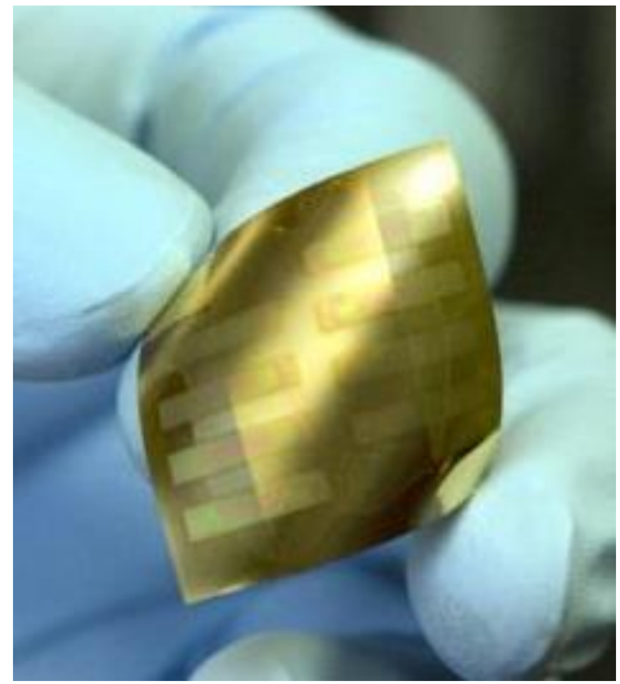
Brittle and heavy

To Lower the Cost of Solar Energy…

Change the way solar cells are made



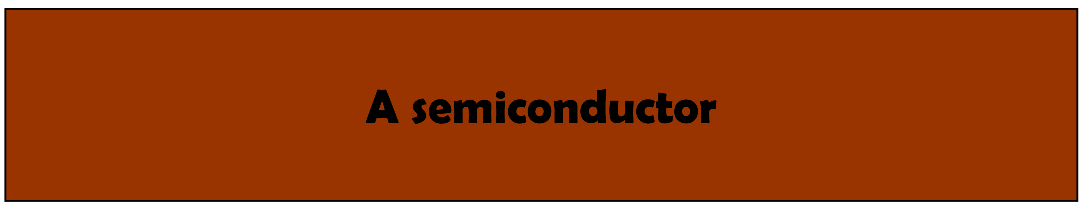
Brittle and heavy



Light and flexible

A Photovoltaic Device
How it works:

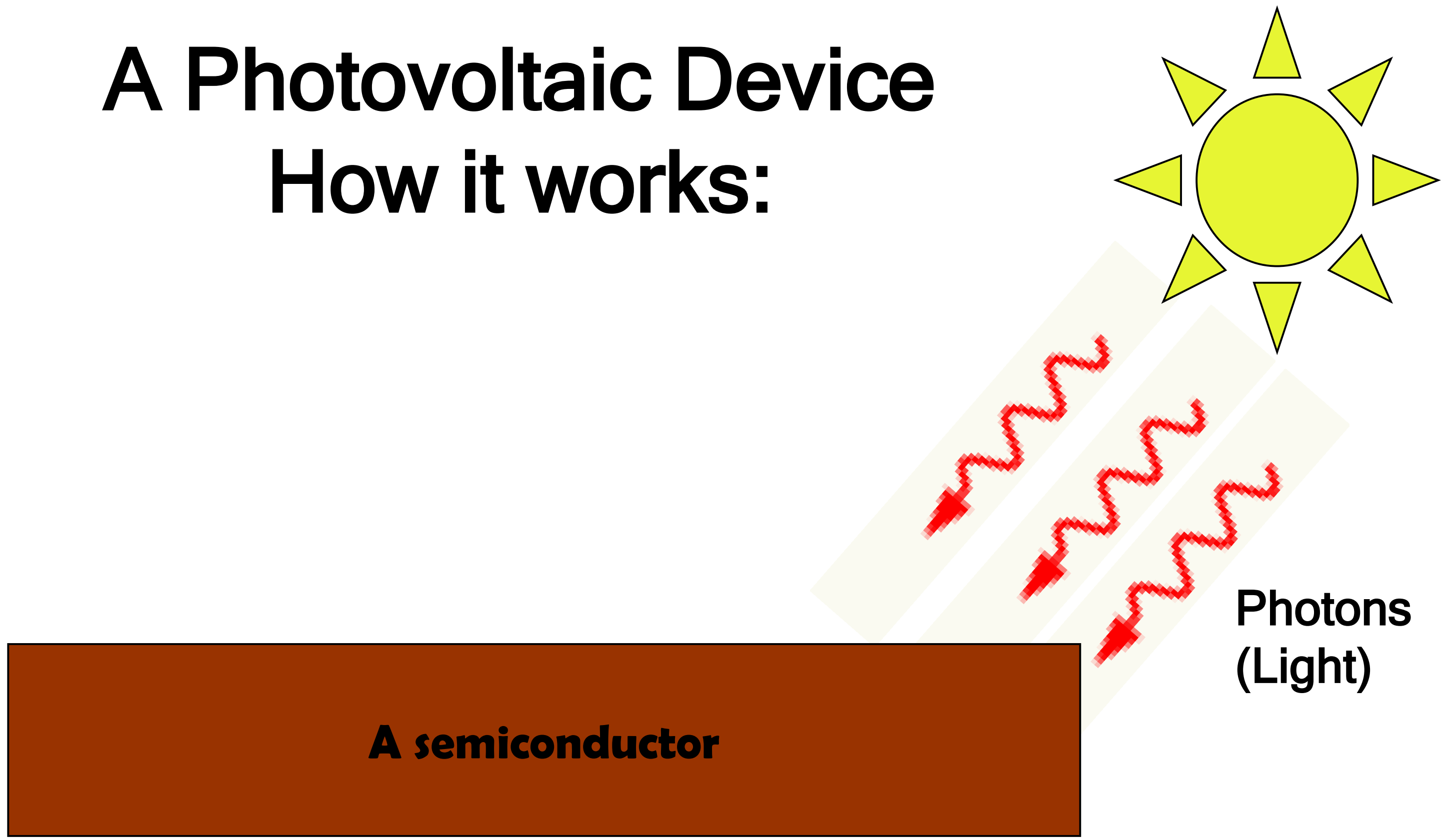
A Photovoltaic Device
How it works:



Start with a <u>semiconductor</u>…

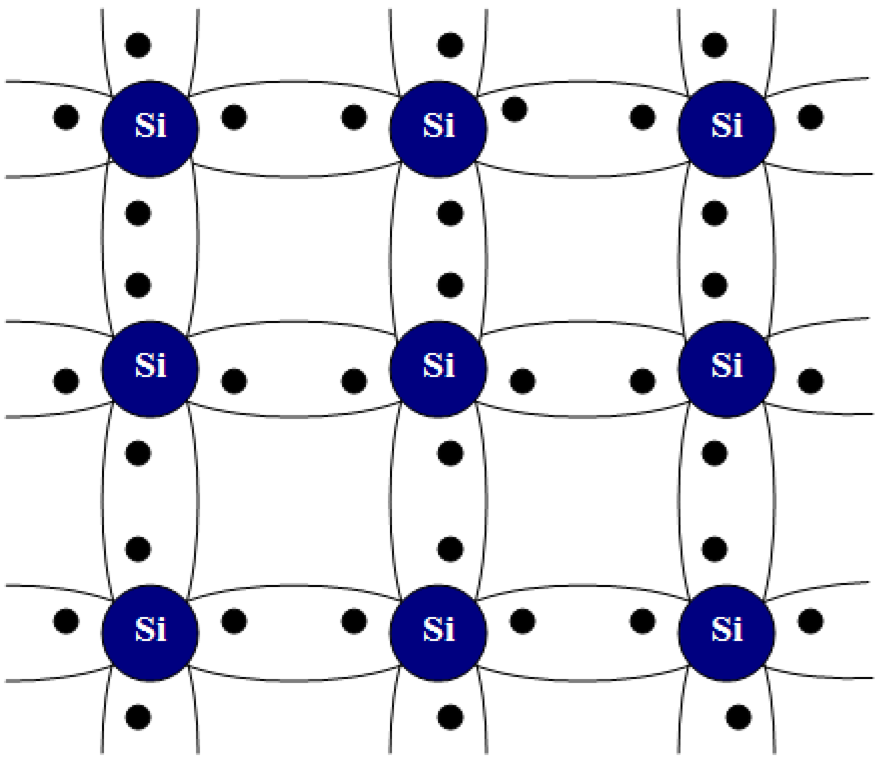
(Examples of semiconductors include silicon, GaN, germanium…)

A Photovoltaic Device
How it works:

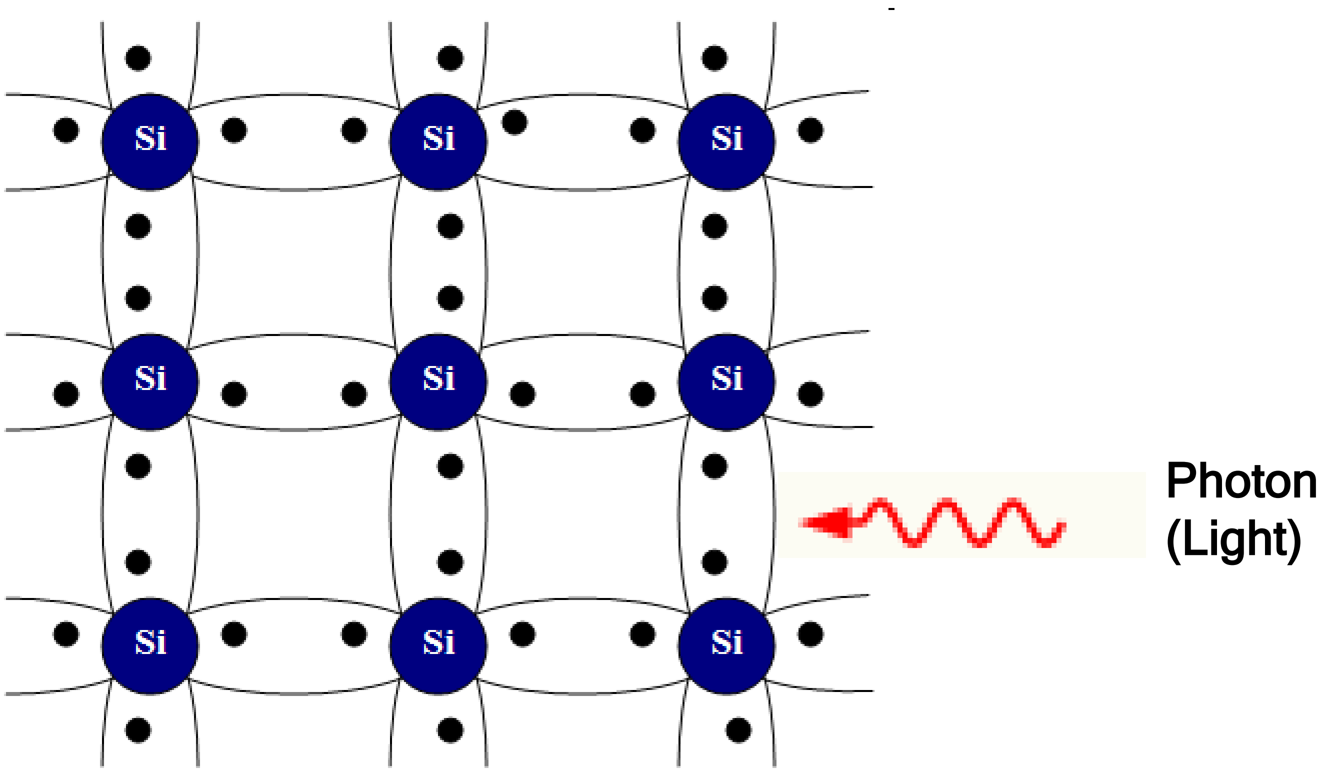


The semiconductor absorbs the light from the sun

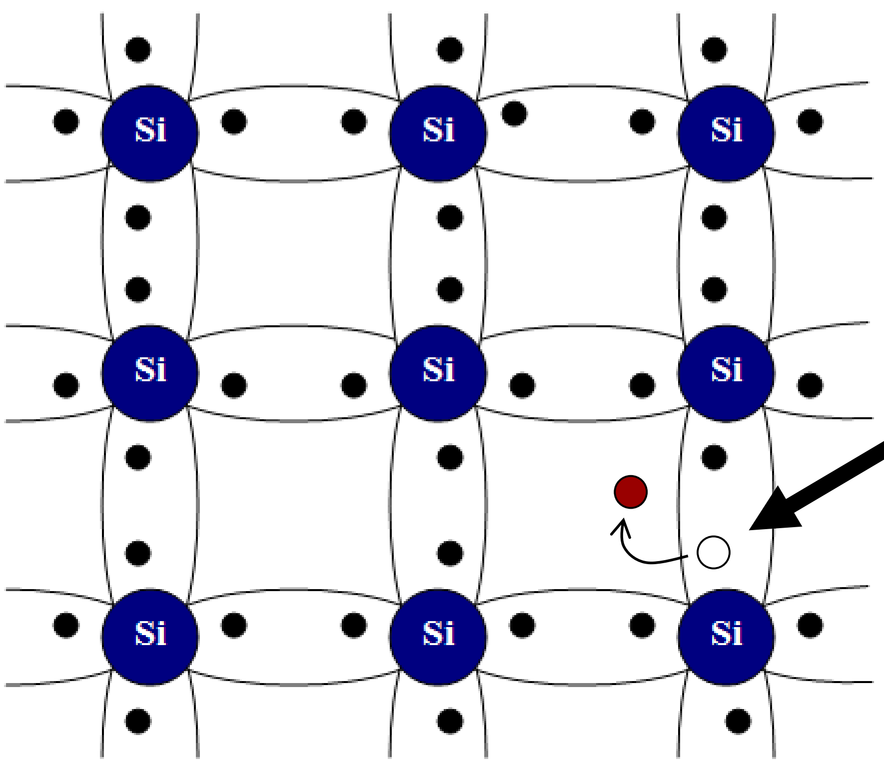
In the semiconductor, electrons are tied up in bonds between atoms



But when the semiconductor absorbs a photon

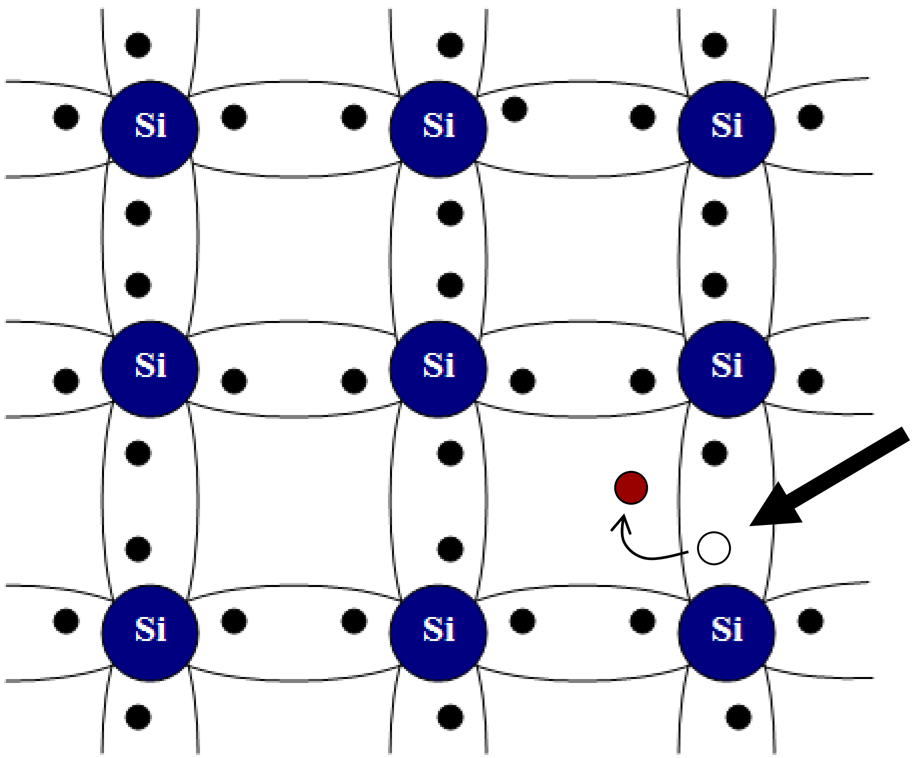


But when the semiconductor absorbs a photon, a free electron is created



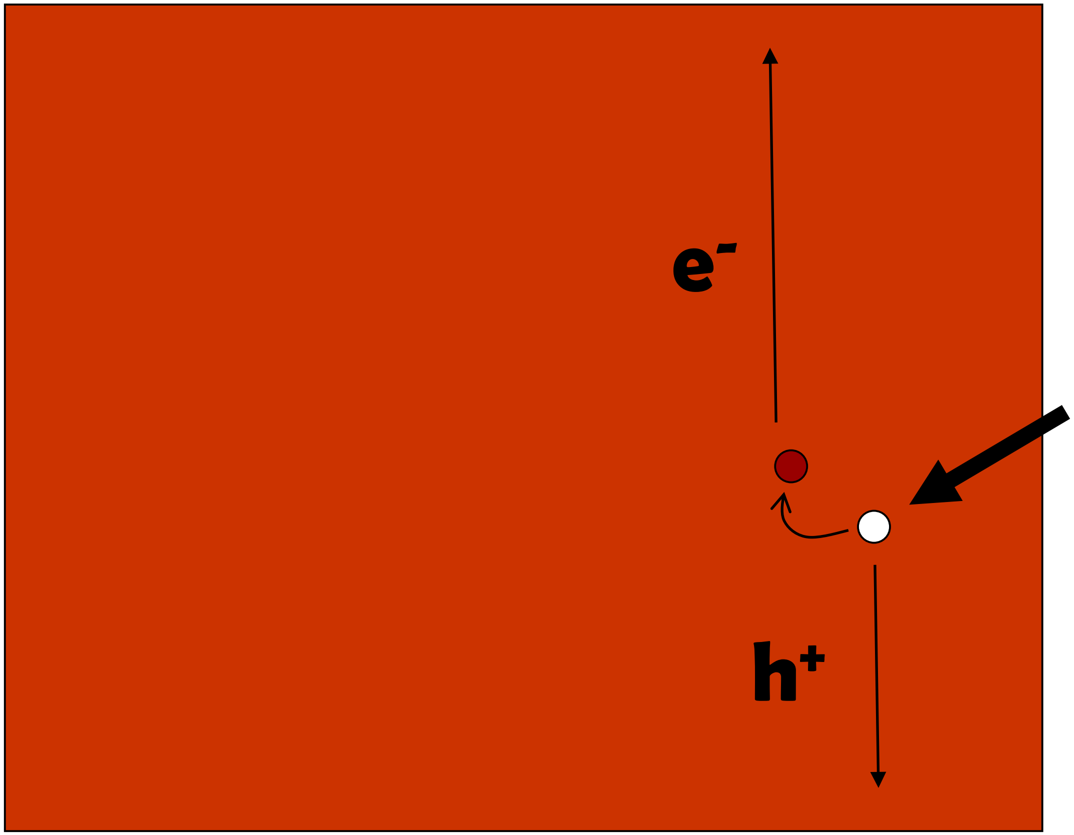
Photon energy "excites" an electron

But when the semiconductor absorbs a photon, a free electron is created and a hole



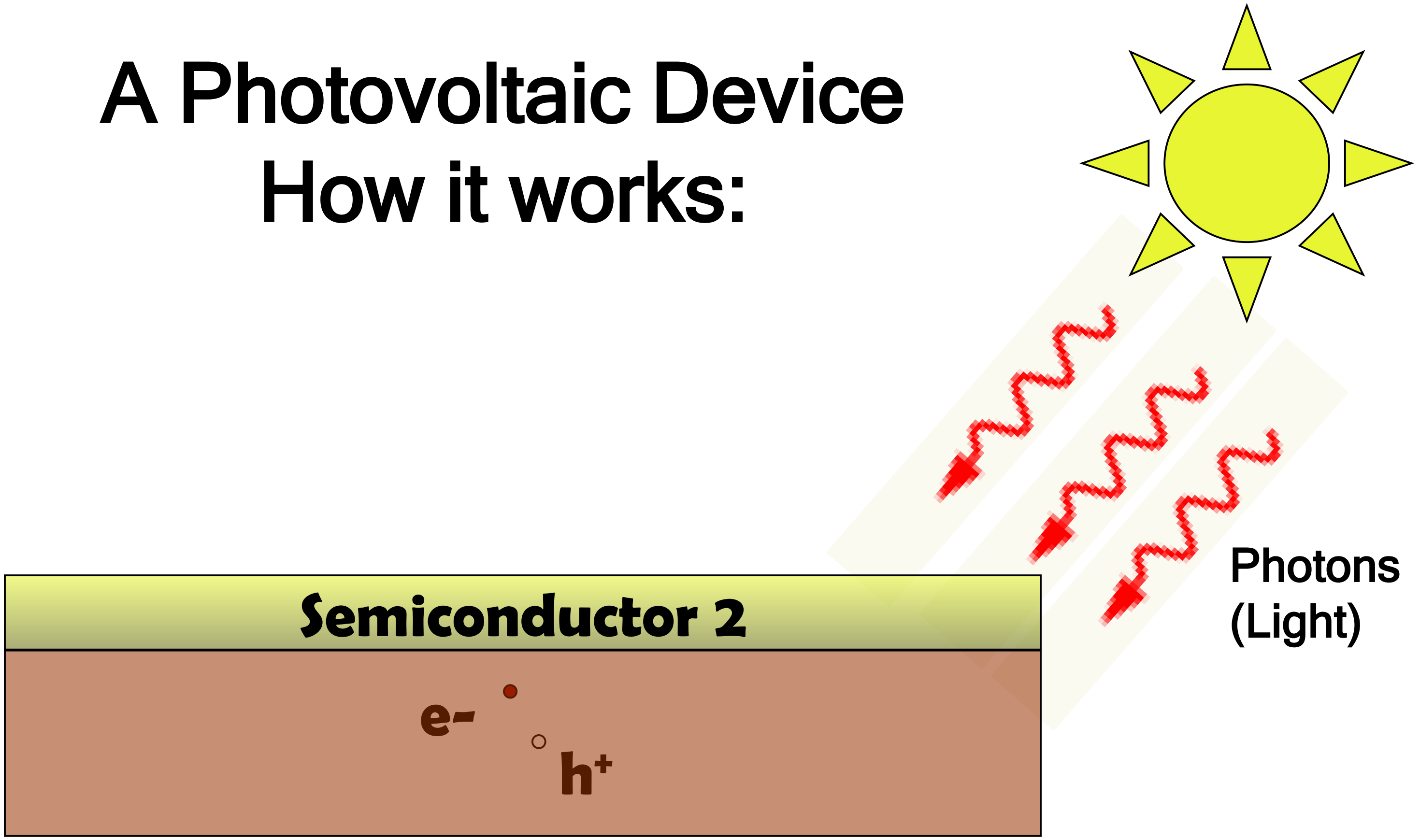
Excited electron leaves behind a *hole*

Both the electron and hole can move to create a photogenerated electrical current across the semiconductor



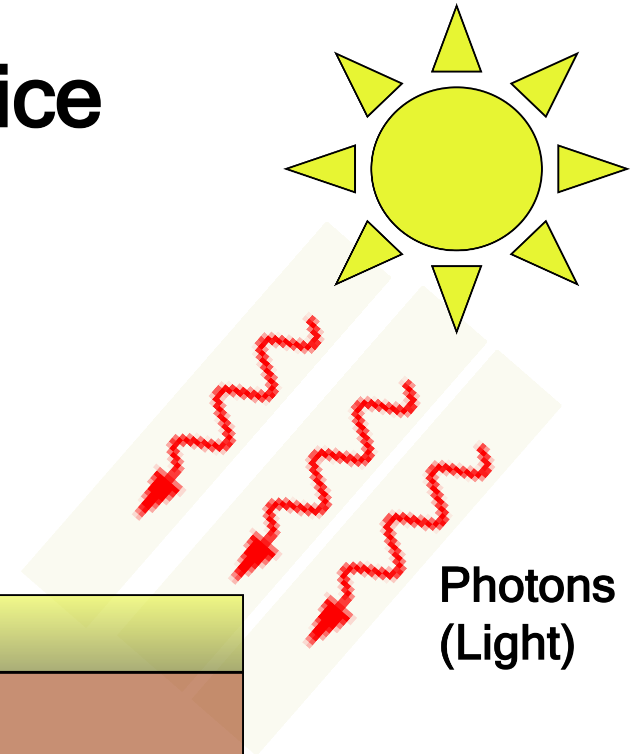
Excited electron and hole can move to create a current

A Photovoltaic Device
How it works:

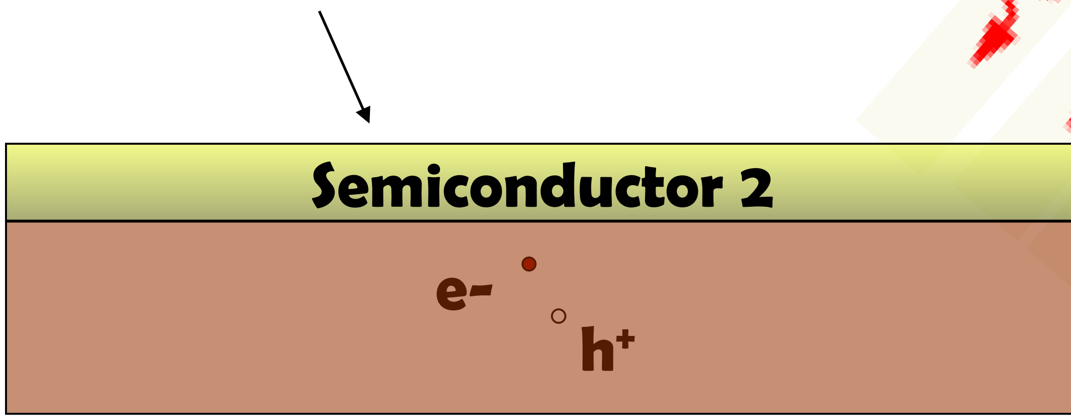


→ Light absorption creates an electron and hole

A Photovoltaic Device
How it works:

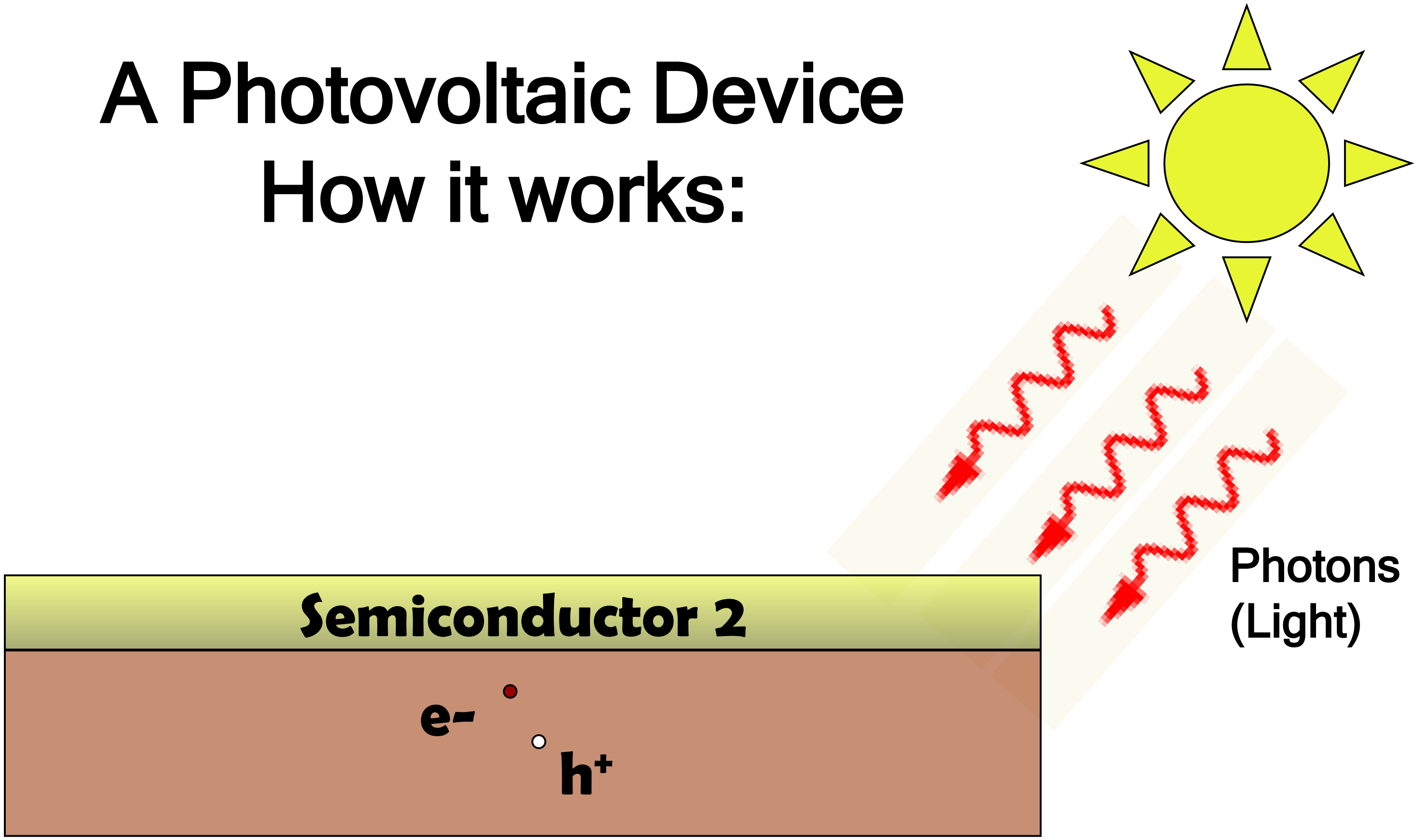


Both the electron and hole can move



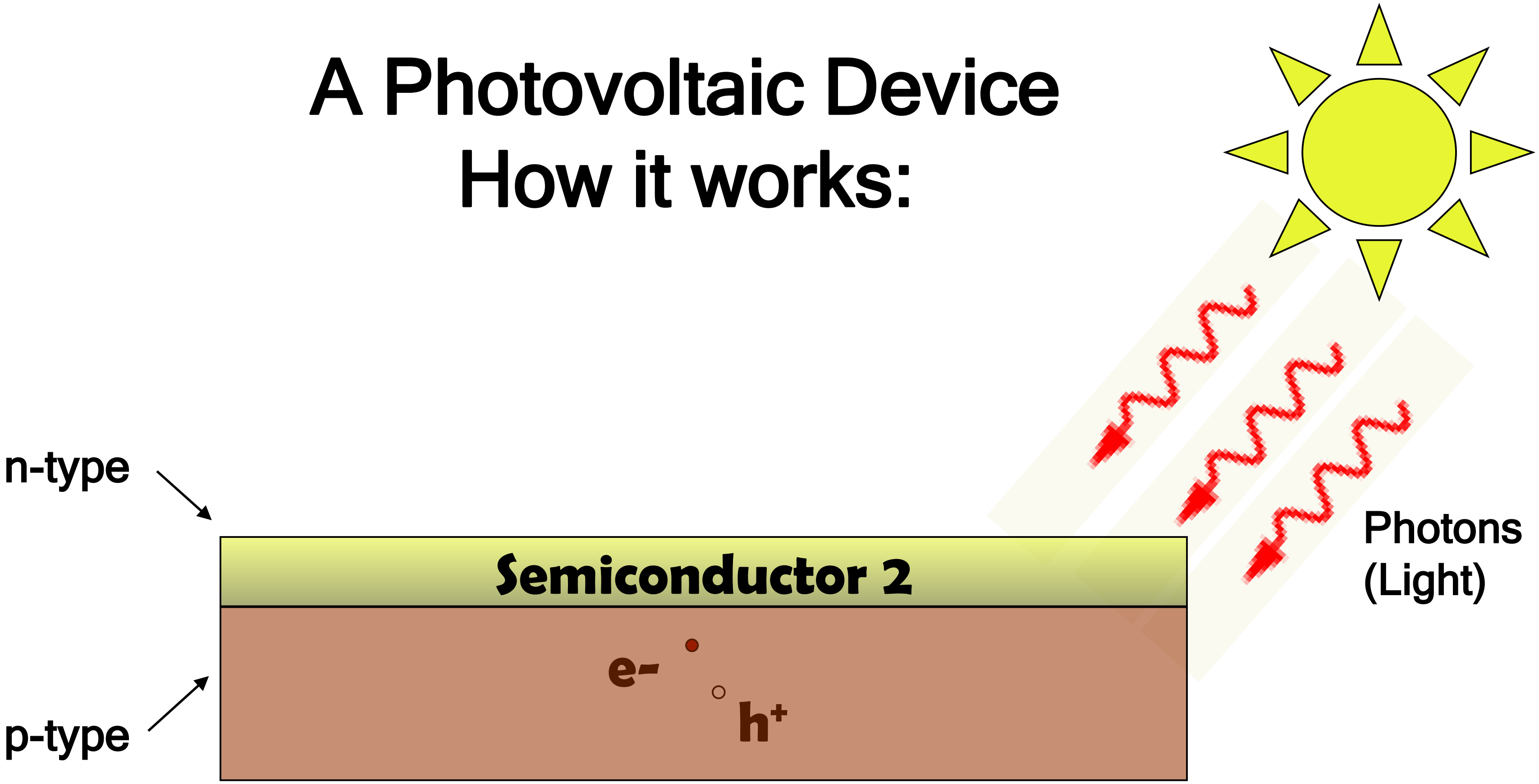
But…need a force that will separate the electron and hole to create an electric current

A Photovoltaic Device
How it works:



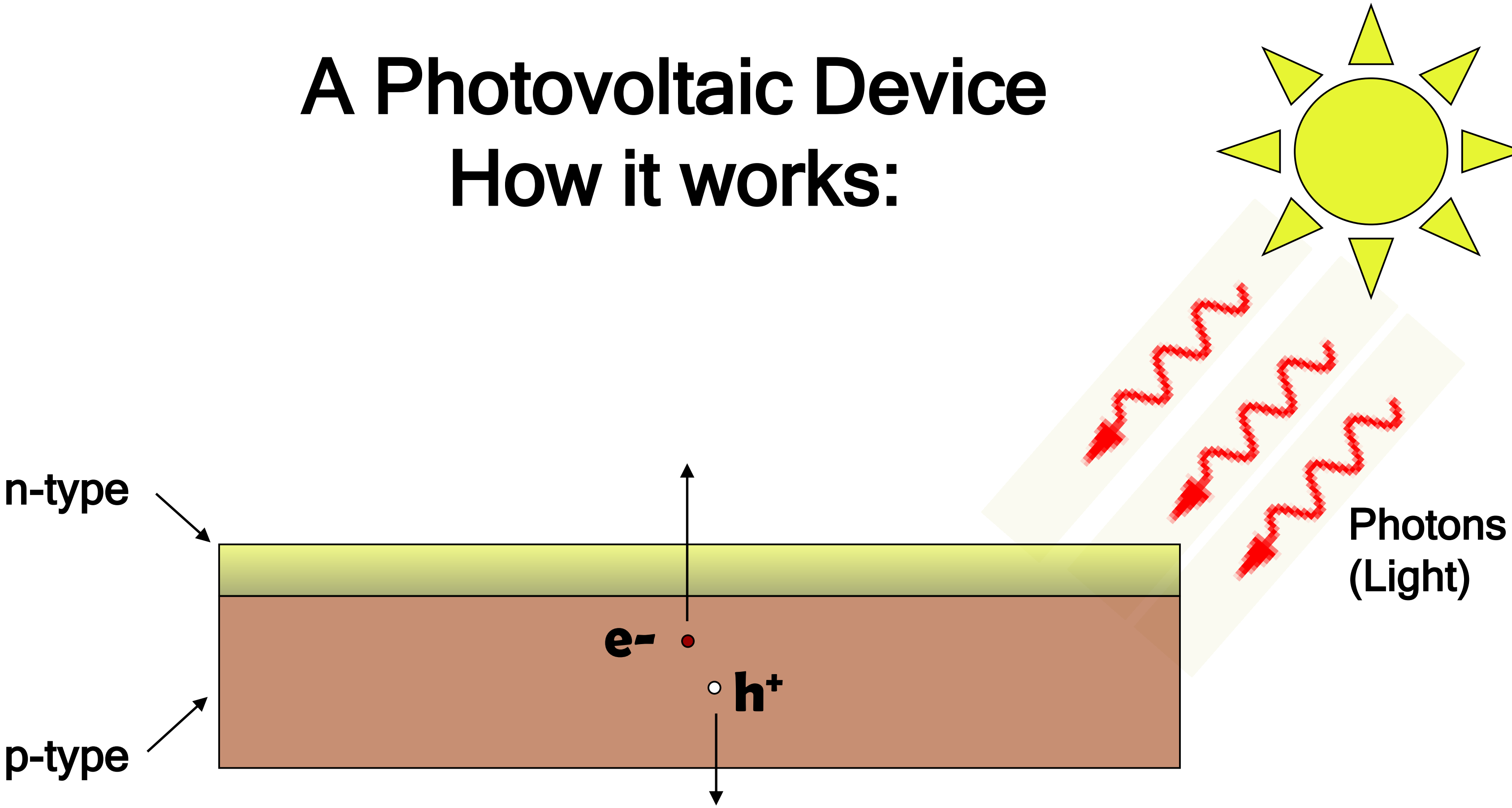
Another semiconductor layer is needed

A Photovoltaic Device
How it works:



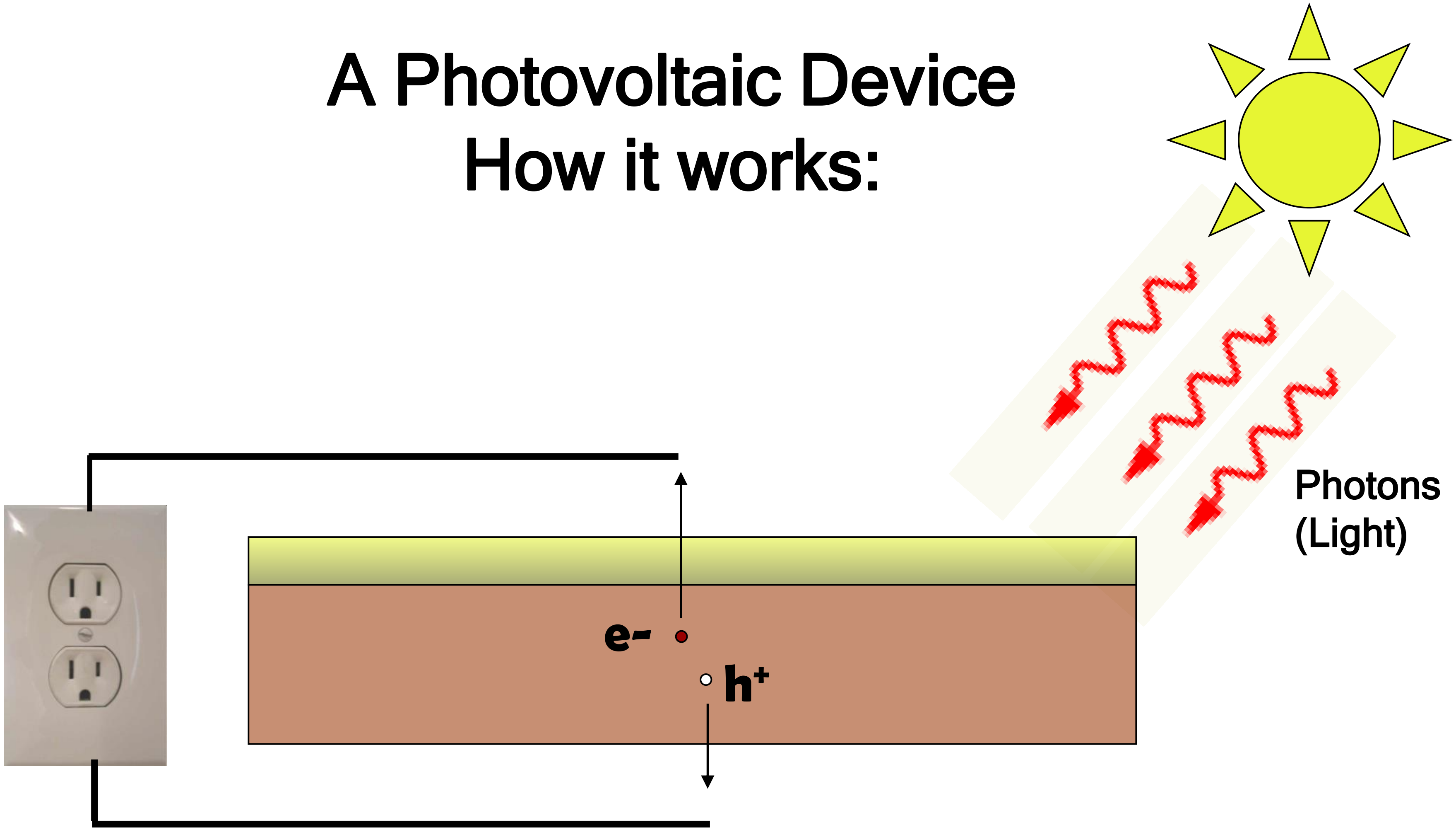
The two semiconductors form a p-n junction

A Photovoltaic Device
How it works:



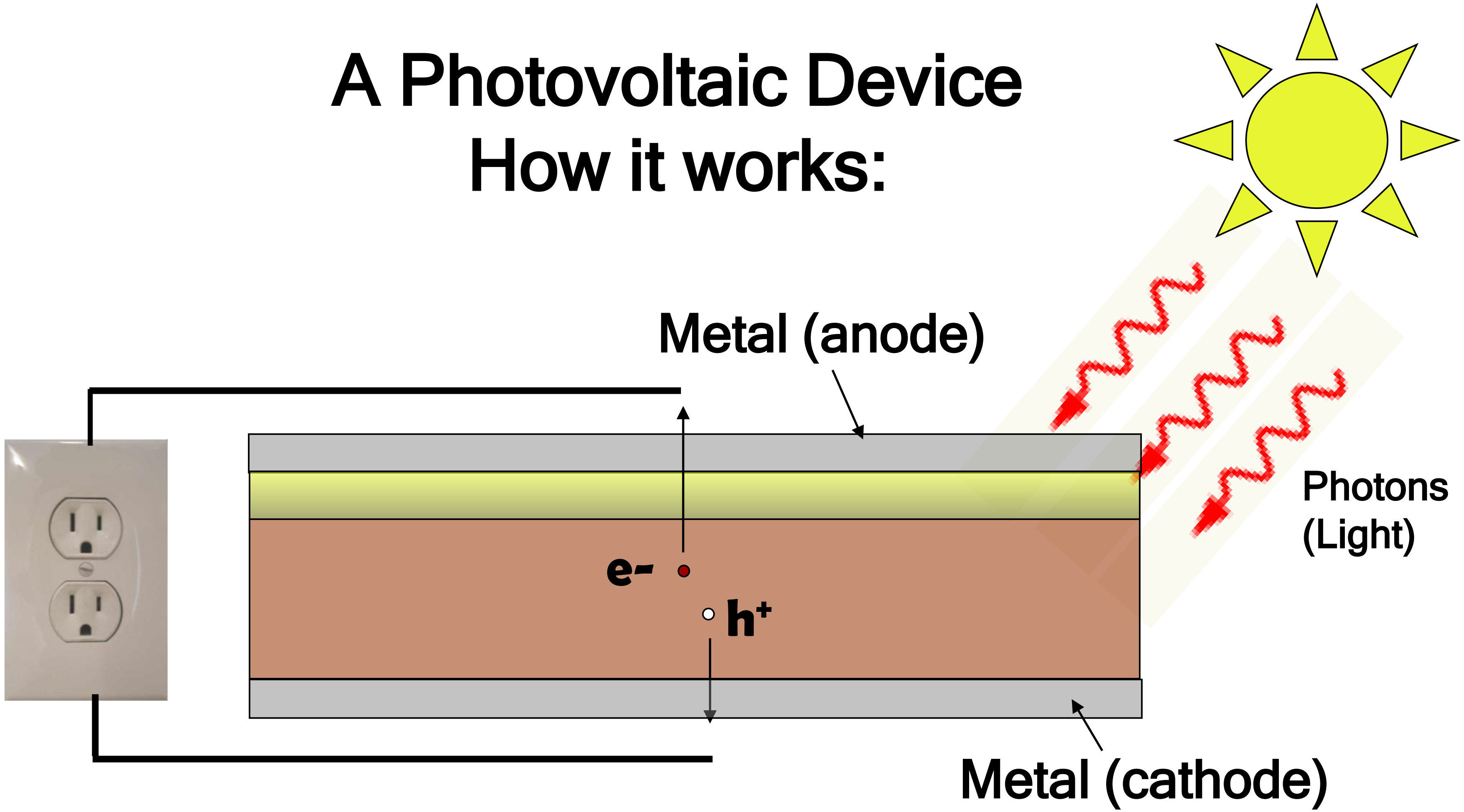
The two semiconductors form a p-n junction that separates the electron and hole; this is the photovoltaic effect

A Photovoltaic Device
How it works:



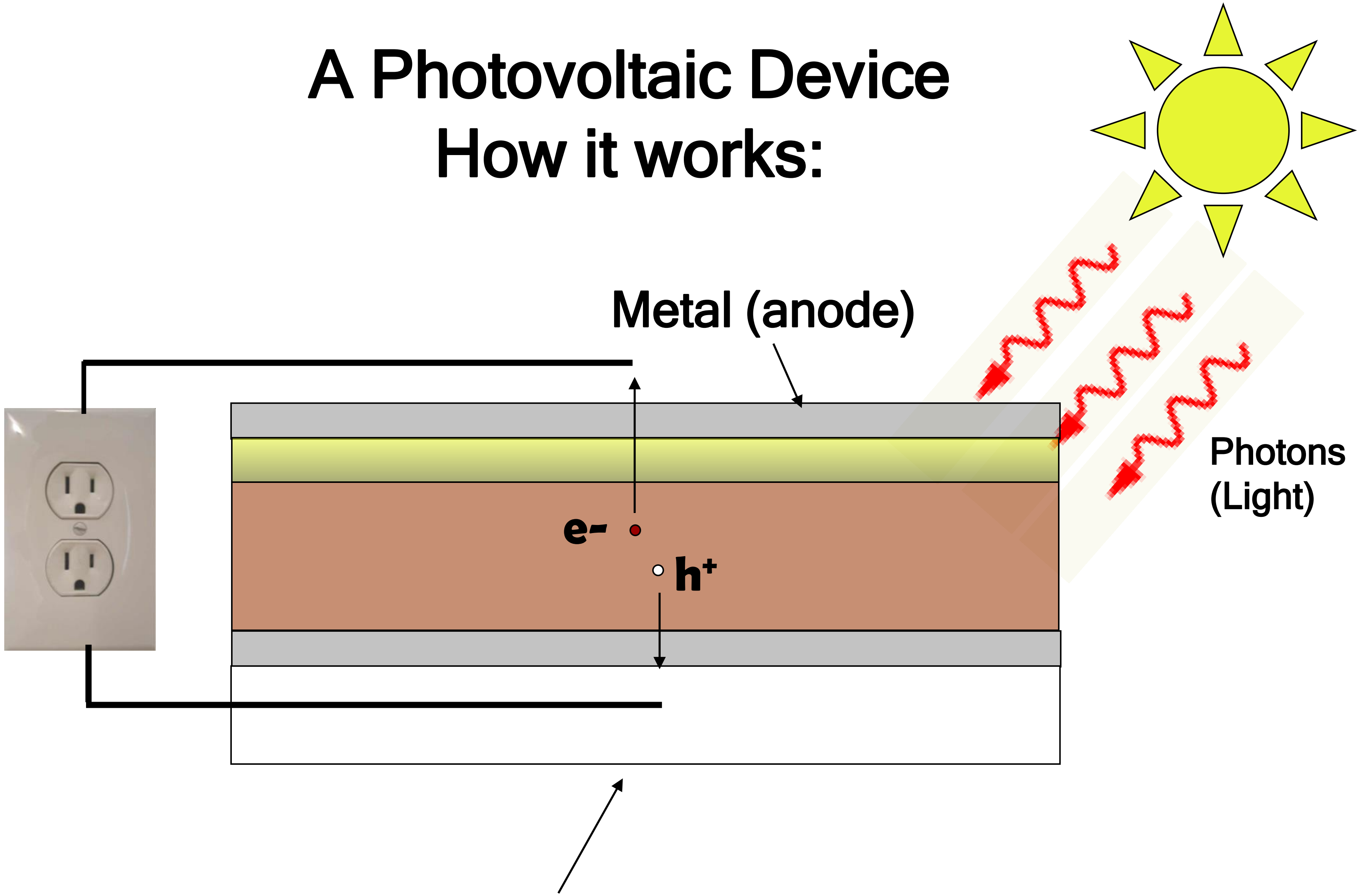
Electrical power can be generated

A Photovoltaic Device
How it works:



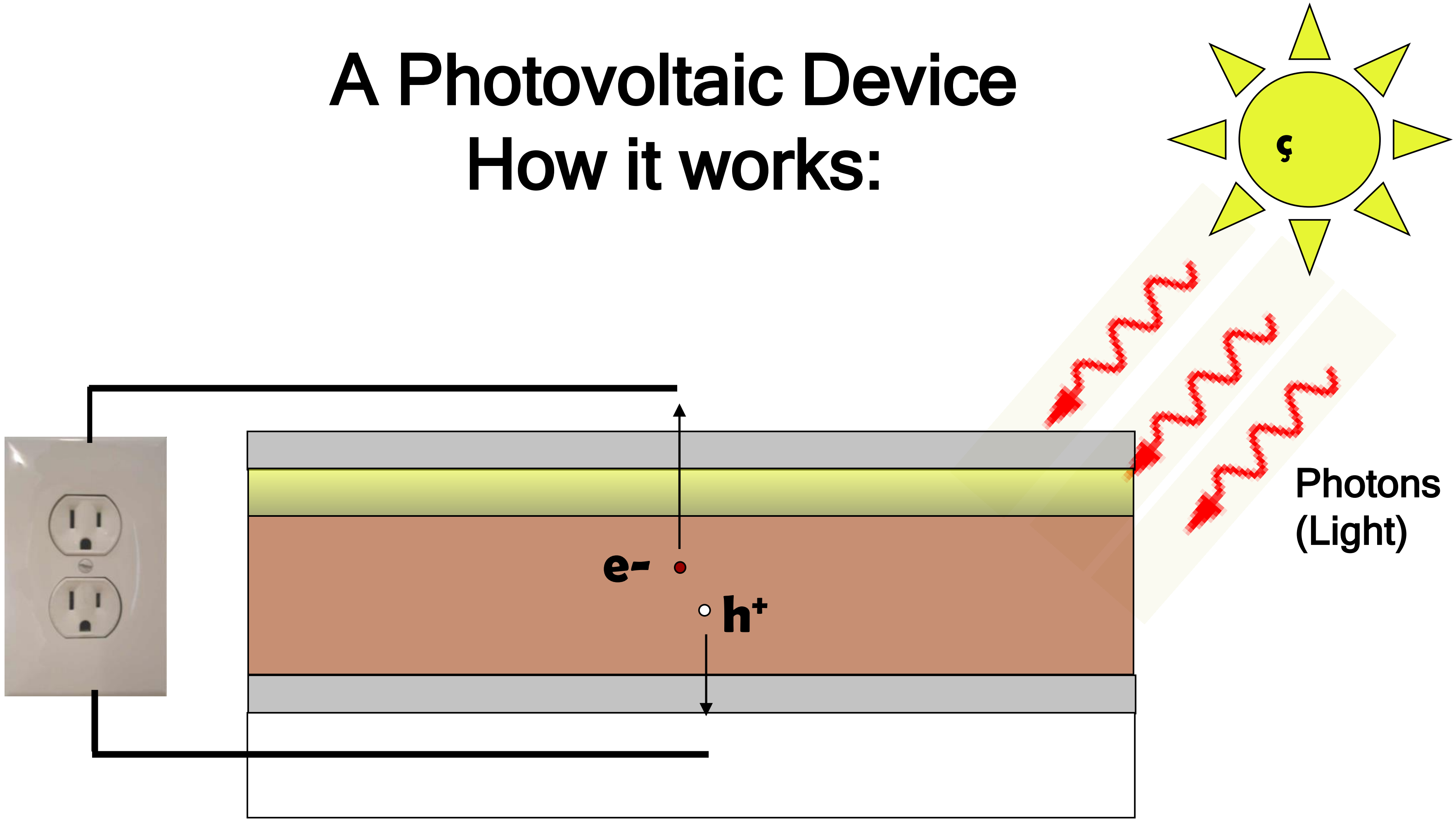
But we need metal electrodes on each side to extract the charge

A Photovoltaic Device
How it works:



And a mechanical support

A Photovoltaic Device
How it works:



This is the basic design of every solar cell

What’s wrong with the existing technology?

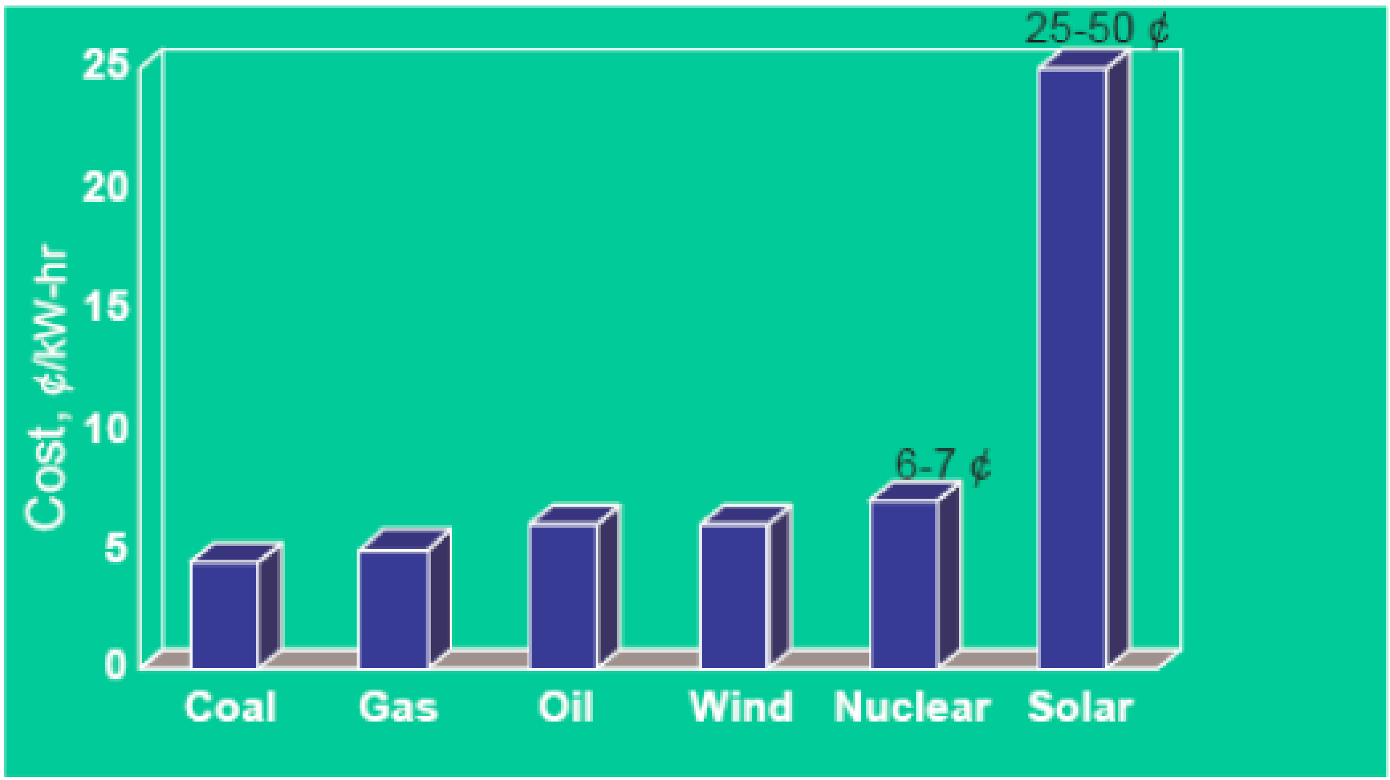
What’s wrong with the existing technology?

What’s wrong with the existing technology?

It’s too expensive

What's wrong with the existing technology?

It's too expensive



Production cost of energy (DOE, 2002)

What's wrong with the existing technology?

To compete with fossil fuels:

- Need < $1/Wp module cost
  - Current cost is $4.27/Wp

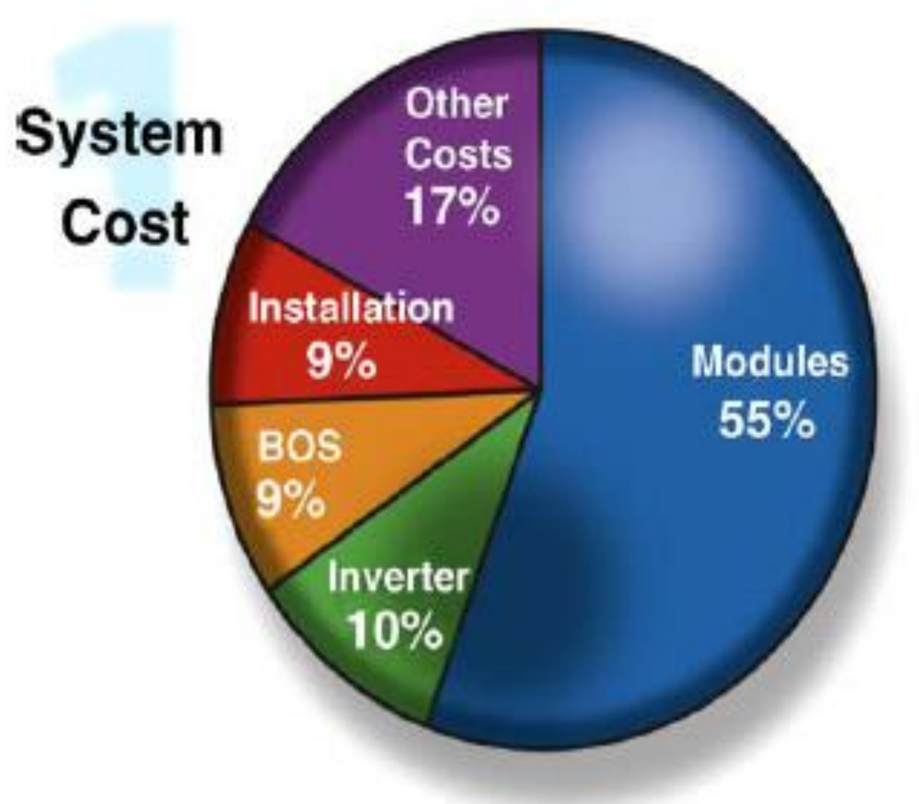
- Cost of power from fossil fuels is <¢4-10/kWh

  -Solar power stands at ¢20/kWh

What's wrong with the existing technology?

- Need < $1/Wp module cost
  - Current cost is $4.27/Wp
- -Corresponds to ~¢20/kWh

55% of the cost is in manufacturing the module



SolarBuzz.com
Kazmerski LL, *J Electron Spectroscopy*, 2006; 150:103–135.

Silicon dominates the solar cell market

Silicon dominates the solar cell market

It’s relatively expensive

1954: the first practical solar cell

Silicon dominates the solar cell market

It's relatively expensive and *mature*

Something New Under the Sun. It's the Bell Solar Battery, made of thin discs of specially treated silicon, an ingredient of common sand. It converts the sun's rays directly into usable amounts of electricity. Simple and trouble-free. (The storage batteries beside the solar battery store up its electricity for night use.)

Bell System Solar Battery Converts Sun's Rays into Electricity!

Bell Telephone Laboratories invention has great possibilities for telephone service and for all mankind

Ever since Archimedes, men have been searching for the secret of the sun.

For it is known that the same kindly rays that help the flowers and the grains and the fruits to grow also send us almost limitless power. It is nearly as much every three days as in all known reserves of coal, oil and uranium.

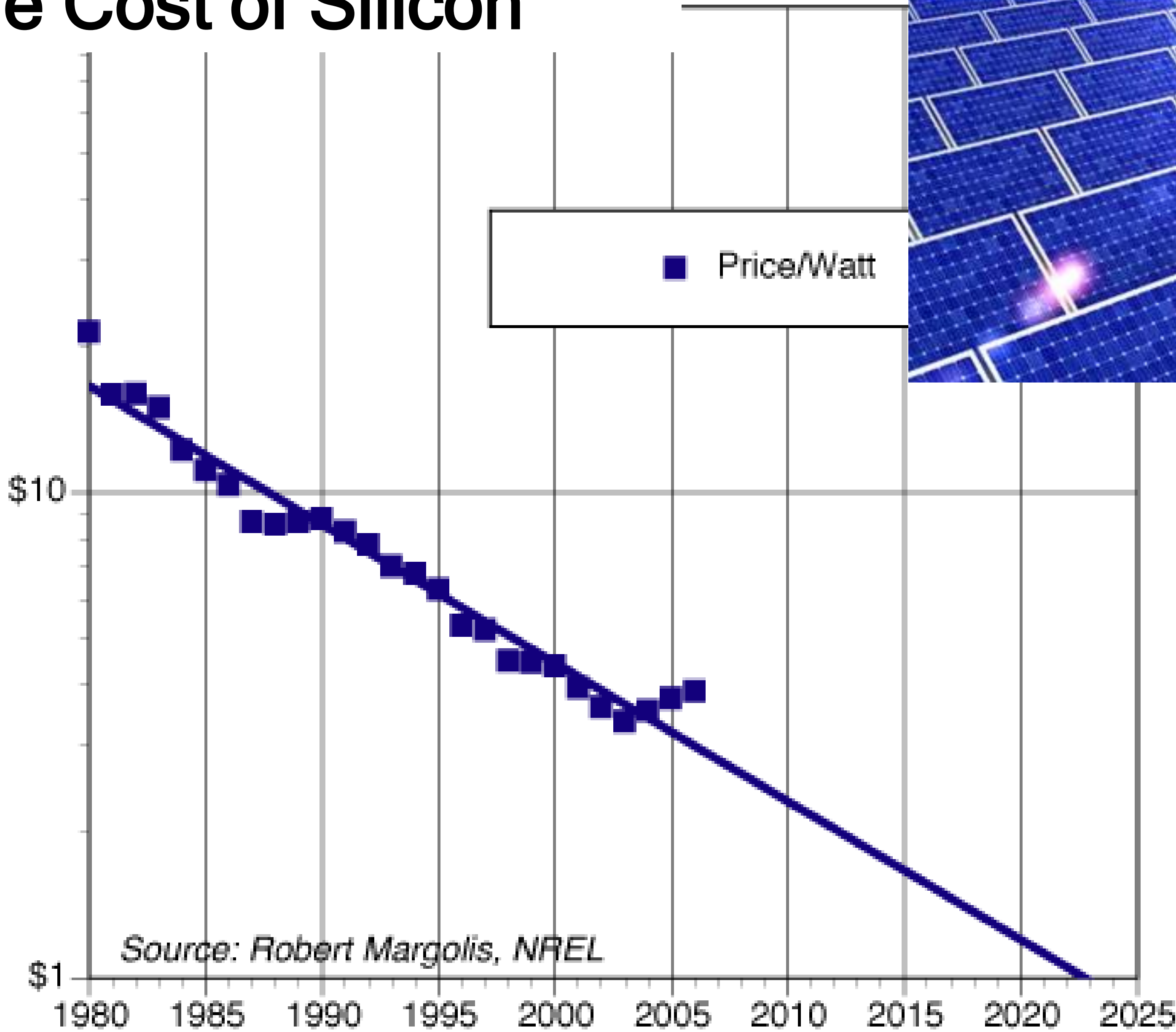
If this energy could be put to use — there would be enough to turn every wheel and light

long research and first announced in 1954. Since then its efficiency has been doubled and its usefulness extended.

There's still much to be done before the battery's possibilities in telephony and for other uses are fully developed. But a good and pioneering start has been made.

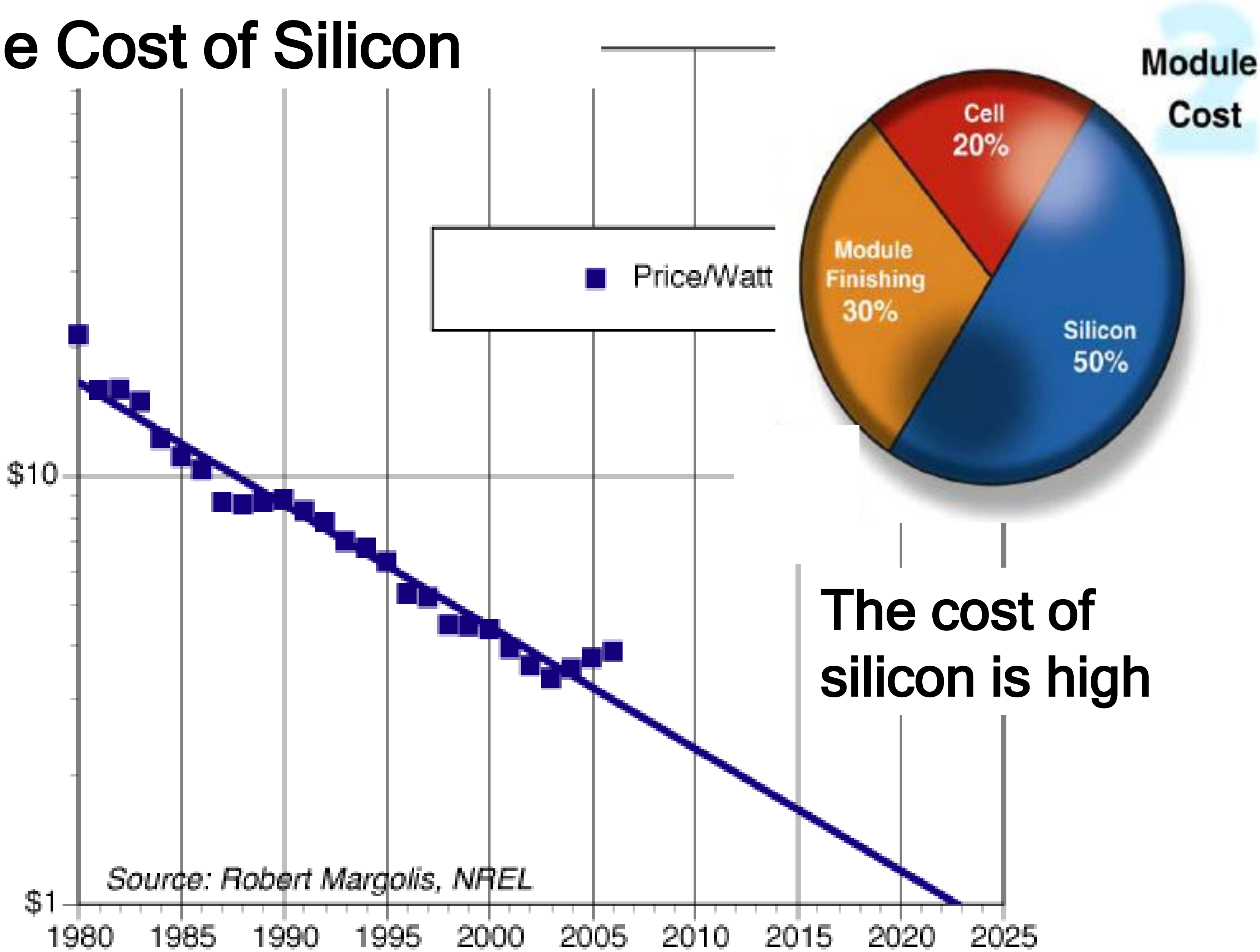
The progress so far is like the opening of a door through which we can glimpse exciting

The Cost of Silicon



http://pubs.usgs.gov/fs/2002/fs087-02/

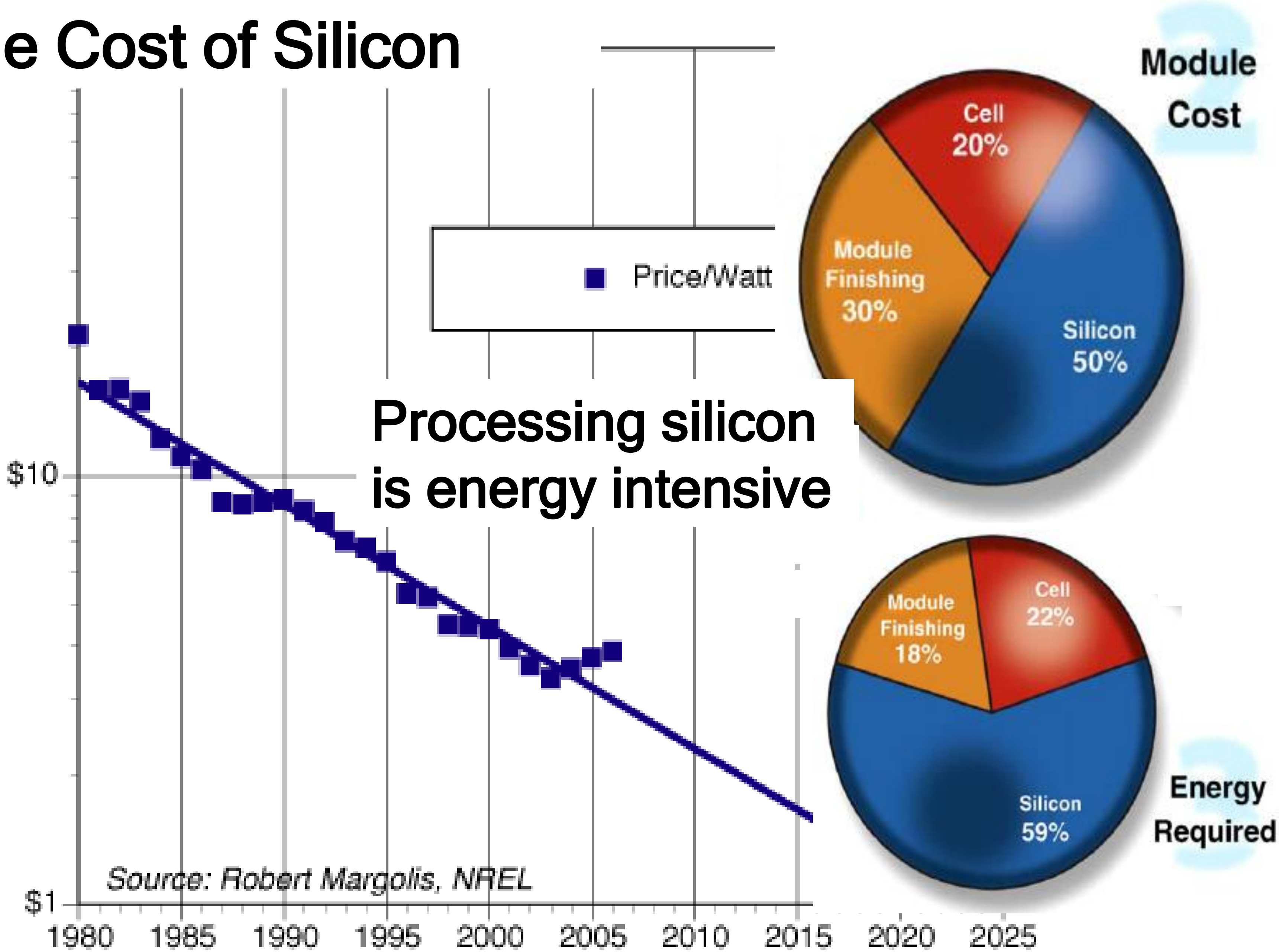
The Cost of Silicon



The cost of silicon is high

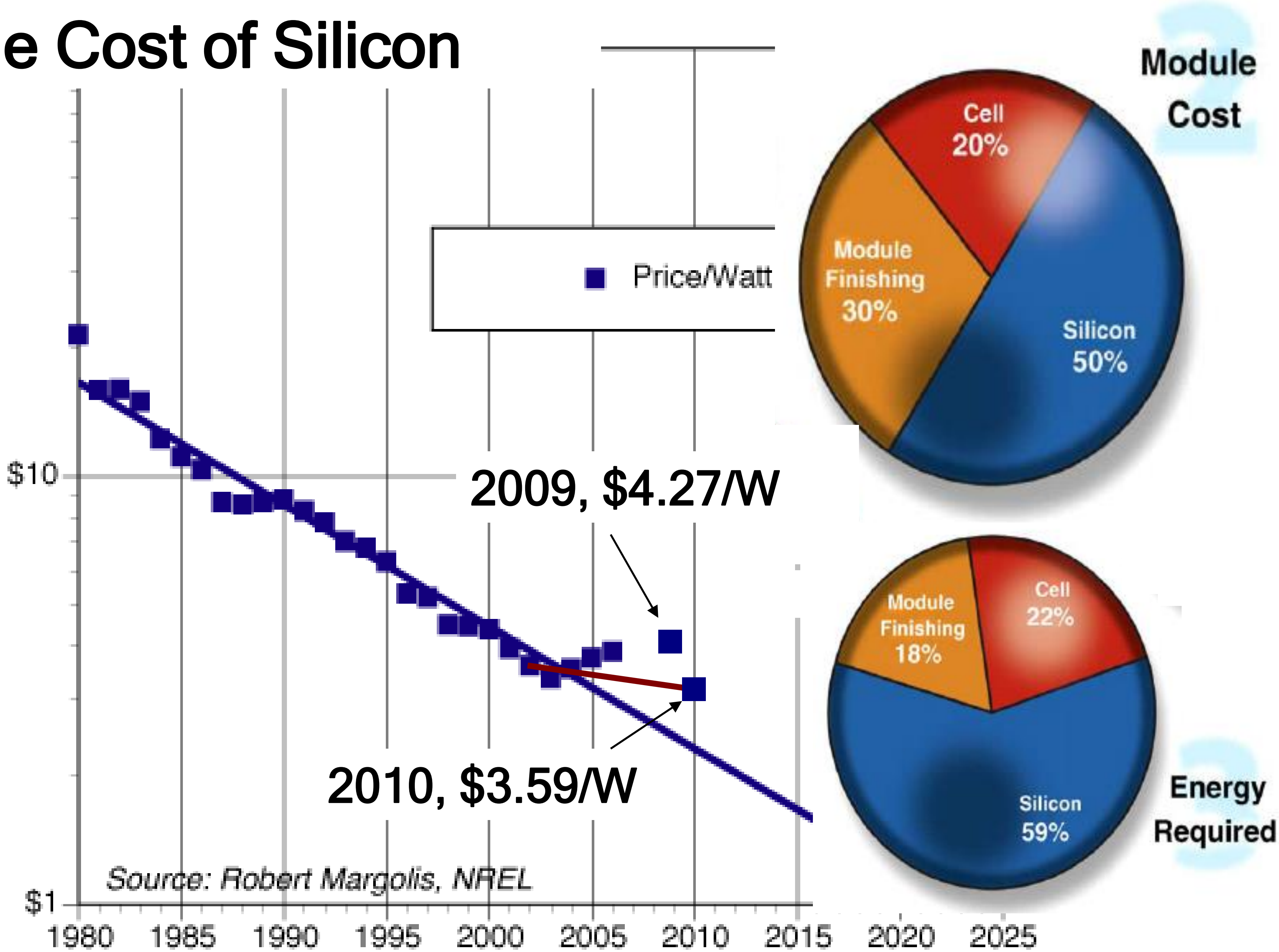
http://pubs.usgs.gov/fs/2002/fs087-02/

The Cost of Silicon



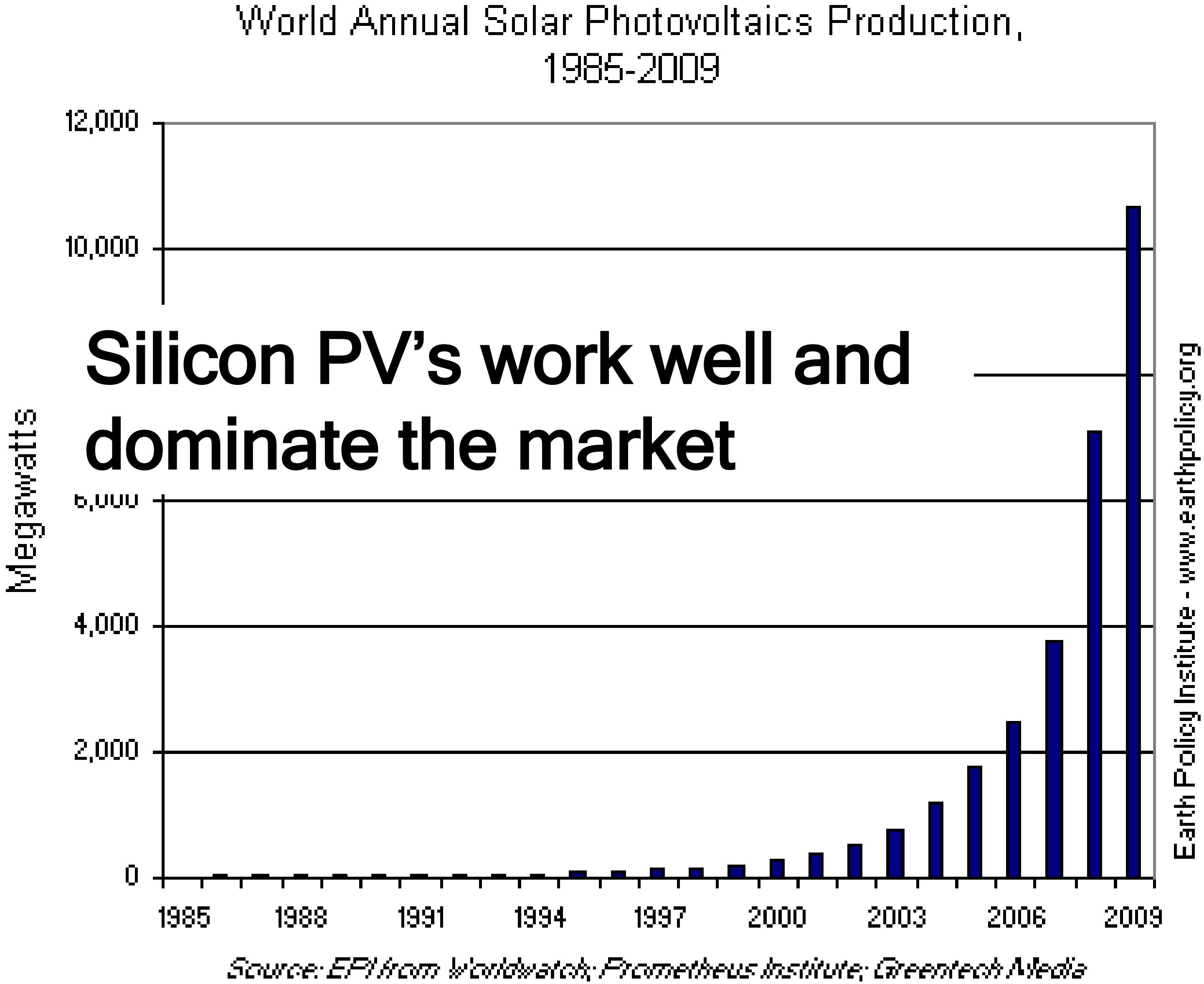
http://pubs.usgs.gov/fs/2002/fs087-02/

The Cost of Silicon



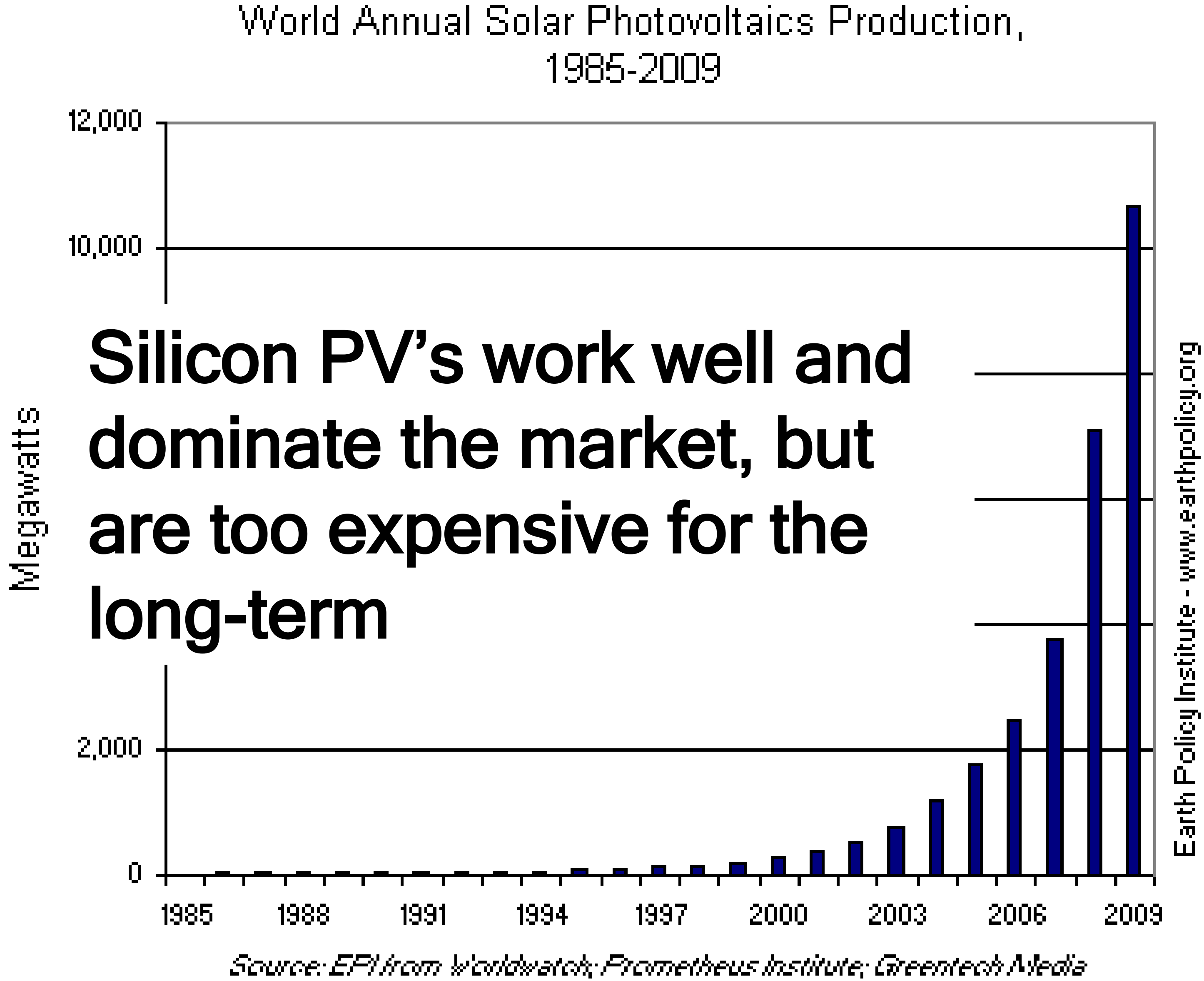
http://pubs.usgs.gov/fs/2002/fs087-02/

Silicon PV's work well and dominate the market



Estimated 14,000 MW capacity in 2010

-



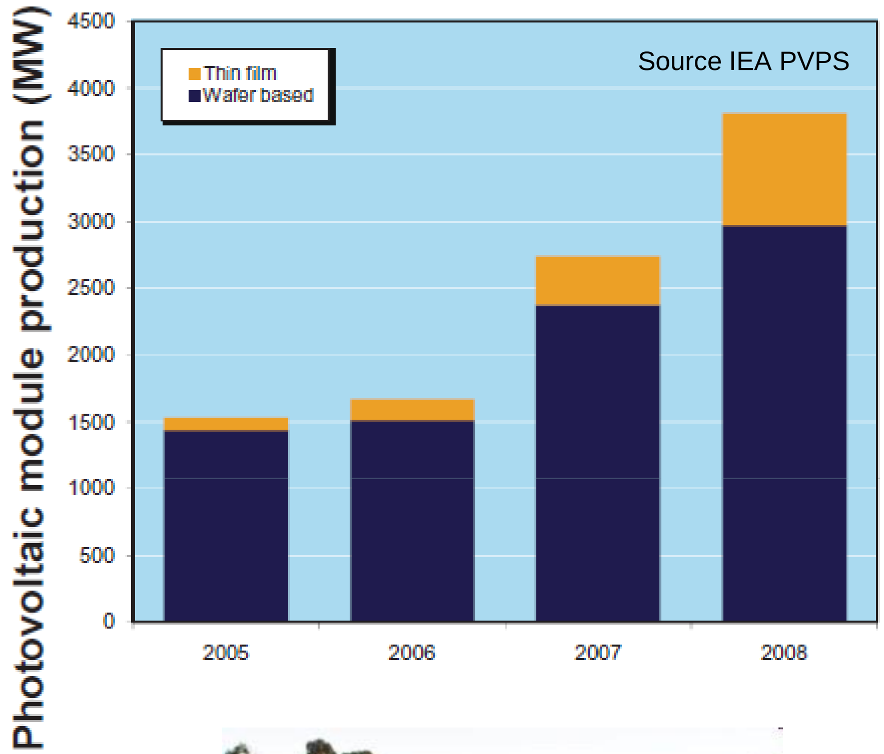
Silicon PV's work well and dominate the market, but are too expensive for the long-term

Estimated 14,000 MW capacity in 2010

There are new Technologies on the Horizon:

There are new Technologies on the Horizon:

CdTe-based thin film solar cells:
First Solar claims to have built modules at $0.98/W

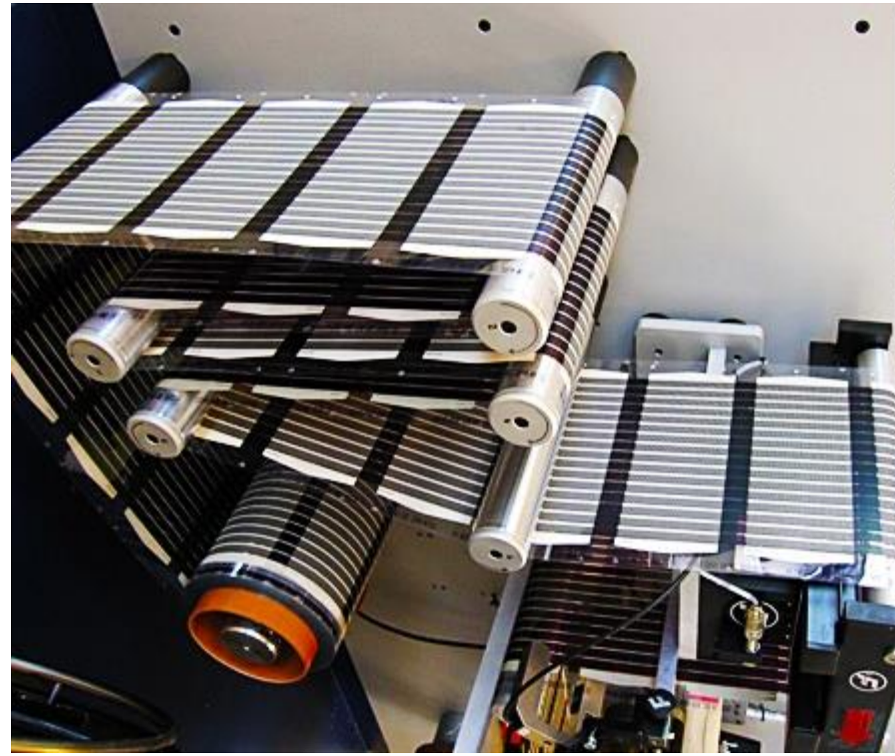


Rooftop First Solar CdTe panels

There are new Technologies on the Horizon:

Organic materials-based solar cells

Konarka



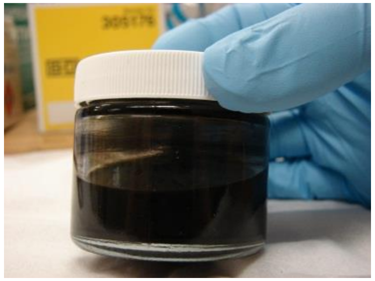
Roll-to-roll processing of polymer-based solar cells (Mekoprint A/S)

There are new Technologies on the Horizon:

But the cost of solar energy still needs to be reduced by about a factor of 10.

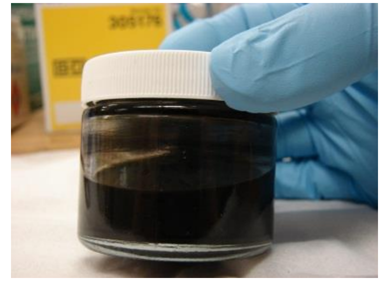
Can we make a “solar” paint that can convert sunlight energy into electricity?

100 nm

First, we need an ink: 

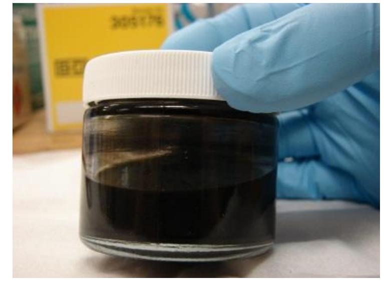
Copper indium gallium selenide: CIGS

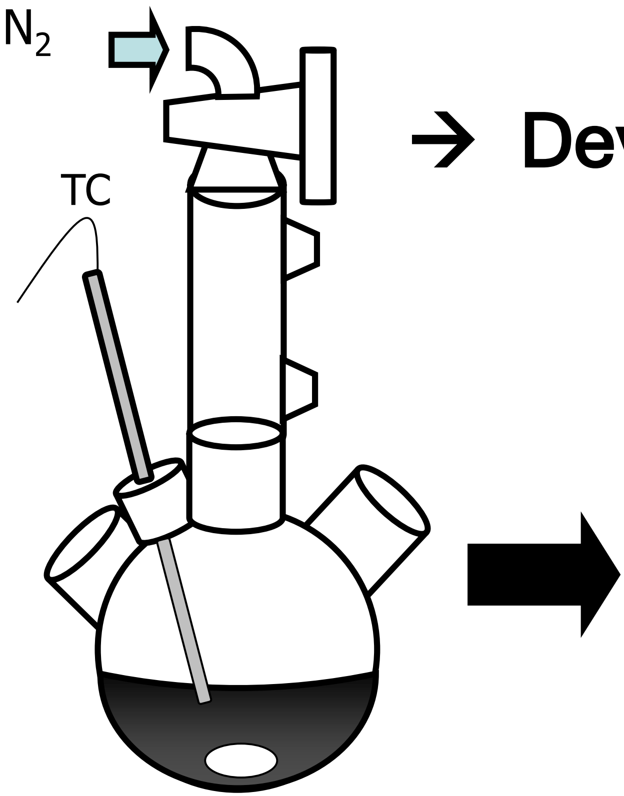
First, we need an ink:



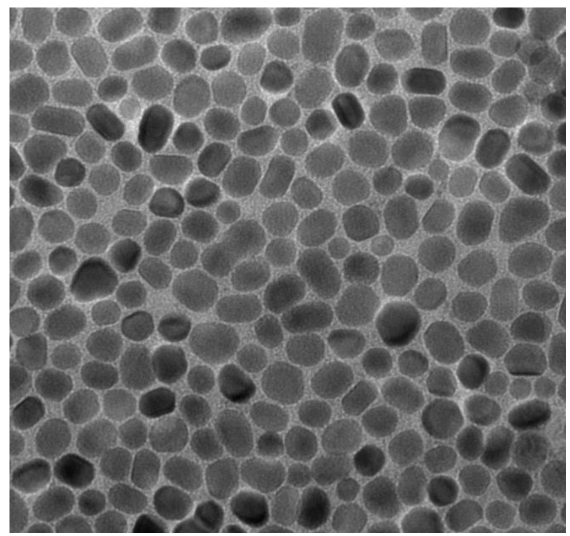
→ Develop a chemical synthesis of CIGS nanocrystals

First, we need an ink:



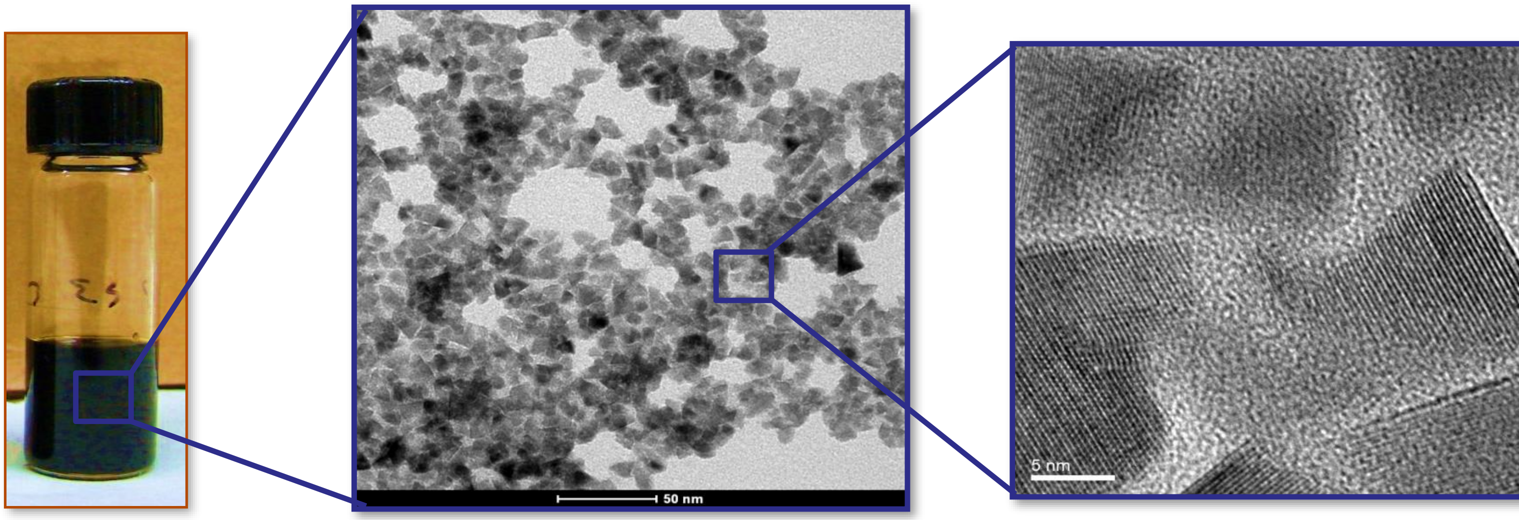


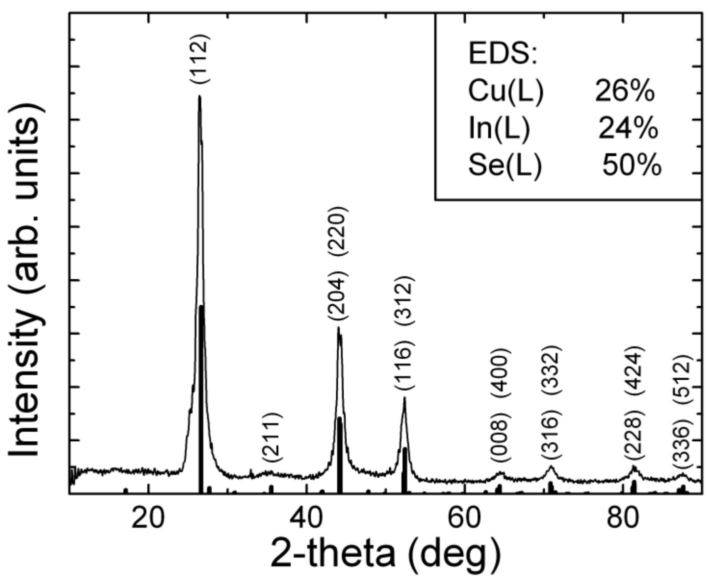
→ Develop a chemical synthesis of CIGS nanocrystals

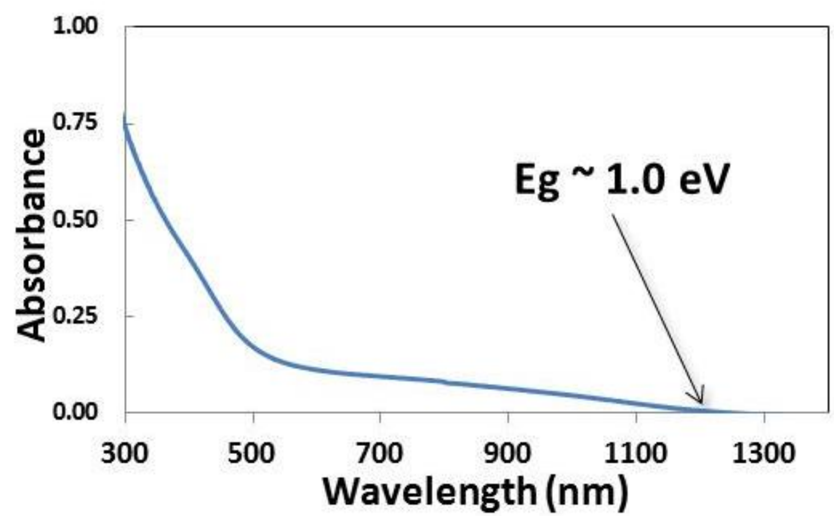


$$\mathrm{CuCl} + \mathrm{InCl_3} + 2\mathrm{Se} \xrightarrow{\text{oleylamine, } 240^{o}\mathrm{C}} \mathrm{CuInSe_2}\ \text{nanocrystals}$$

15 - 20 nm diameter $CuInSe_2$ nanocrystals







JACS ARTICLES
Published on Web 11/17/2008

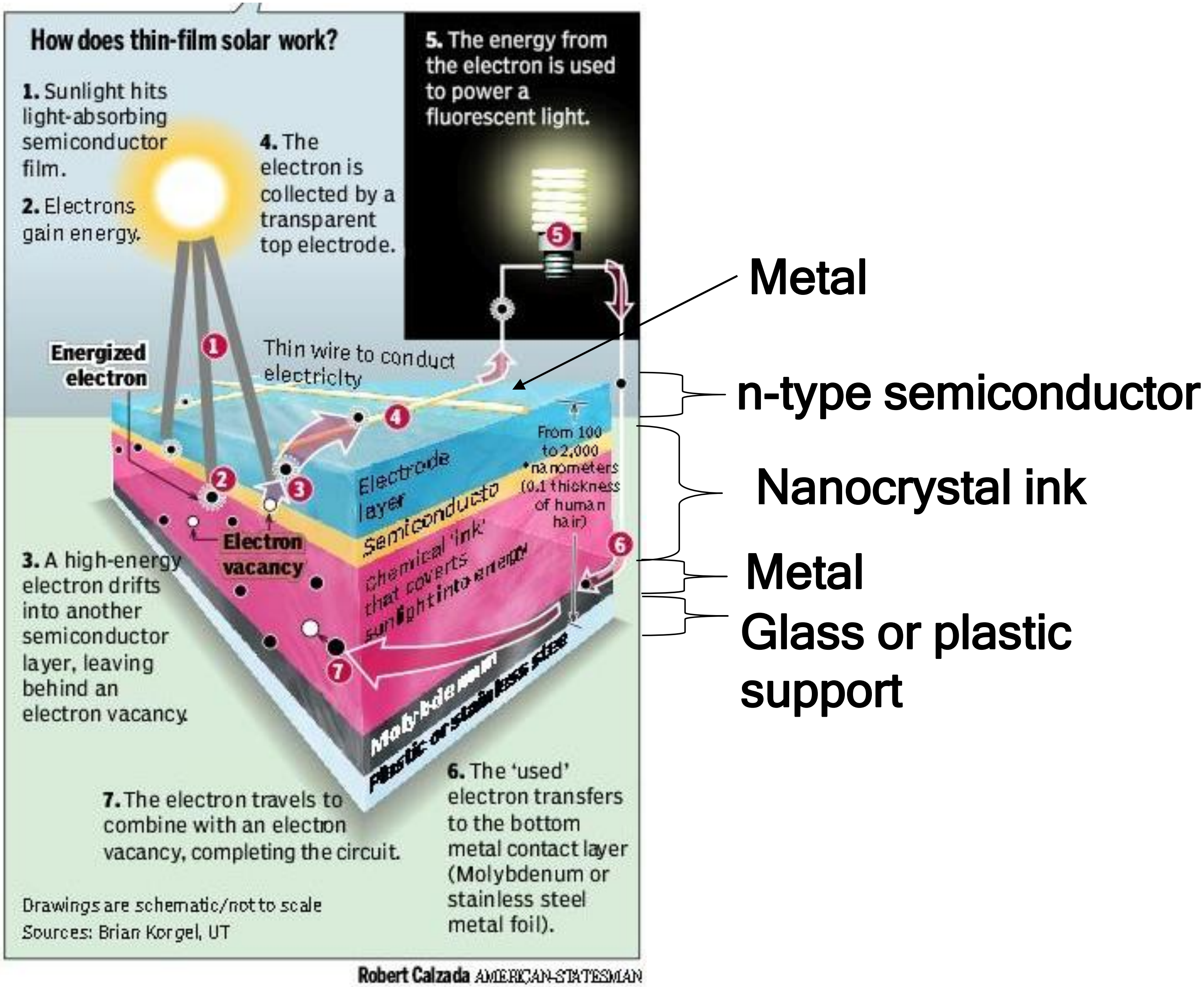
Synthesis of $CuInS_2$, $CuInSe_2$, and $Cu(In_xGa_{1-x})Se_2$ (CIGS) Nanocrystal “Inks” for Printable Photovoltaics

Matthew G. Panthani,[†] Vahid Akhavan,[†] Brian Goodfellow,[†] Johanna P. Schmidtke,[‡] Lawrence Dunn,[§,||] Ananth Dodabalapur,[§] Paul F. Barbara,[‡] and Brian A. Korgel[*,†]

Departments of Chemical Engineering, Chemistry & Biochemistry, and Physics and Microelectronics Research Center, Texas Materials Institute and Center for Nano- and Molecular Science and Technology, The University of Texas at Austin, Austin, Texas 78712-1062

Received July 25, 2008; E-mail: korgel@che.utexas.edu

Abstract: Chalcopyrite copper indium sulfide ($CuInS_2$) and copper indium gallium selenide ($Cu(In_xGa_{1-x})$-Se_2; CIGS) nanocrystals ranging from ~5 to ~25 nm in diameter were synthesized by arrested precipitation in solution. The In/Ga ratio in the CIGS nanocrystals could be controlled by varying the In/Ga reactant ratio in the reaction, and the optical properties of the $CuInS_2$ and CIGS nanocrystals correspond to those of the respective bulk materials. Using methods developed to produce uniform, crack-free micrometer-thick films, $CuInSe_2$ nanocrystals were tested in prototype photovoltaic devices. As a proof-of-concept, the nanocrystal-based devices exhibited a reproducible photovoltaic response.


How does thin-film solar work?
1. Sunlight hits light-absorbing semiconductor film.
2. Electrons gain energy.
4. The electron is collected by a transparent top electrode.
5. The energy from the electron is used to power a fluorescent light.
Energized electron
Thin wire to conduct electricity
Electrode layer
Semiconductor
chemical 'ink' that coverts sunlight into energy
Molybdenum
Plastic or stainless steel
From 100 to 2,000 nanometers (0.1 thickness of human hair)
Electron vacancy
3. A high-energy electron drifts into another semiconductor layer, leaving behind an electron vacancy.
7. The electron travels to combine with an electron vacancy, completing the circuit.
6. The 'used' electron transfers to the bottom metal contact layer (Molybdenum or stainless steel metal foil).
Drawings are schematic/not to scale
Sources: Brian Korgel, UT
Robert Calzada AMERICAN-STATESMAN
Metal
n-type semiconductor
Nanocrystal ink
Metal
Glass or plastic support

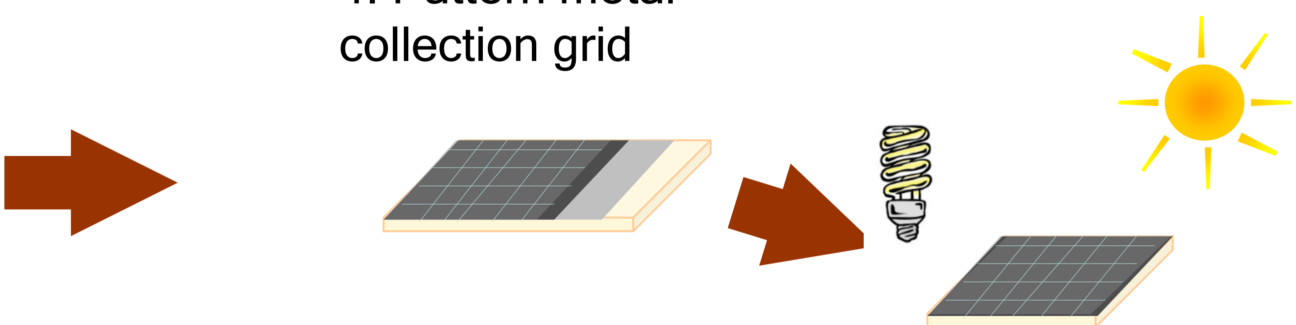
Nanocrystal PV Device Fabrication

1. Deposit metal foil onto a flexible substrate

2. Solution-deposit nanocrystals

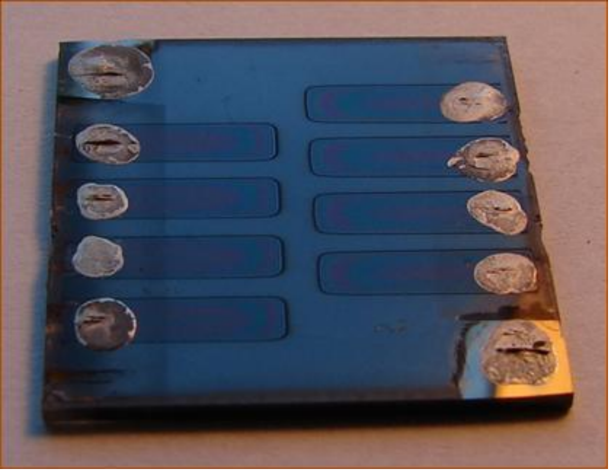
3. Deposit heterojunction partner layers (CdS/ZnO)

4. Pattern metal collection grid



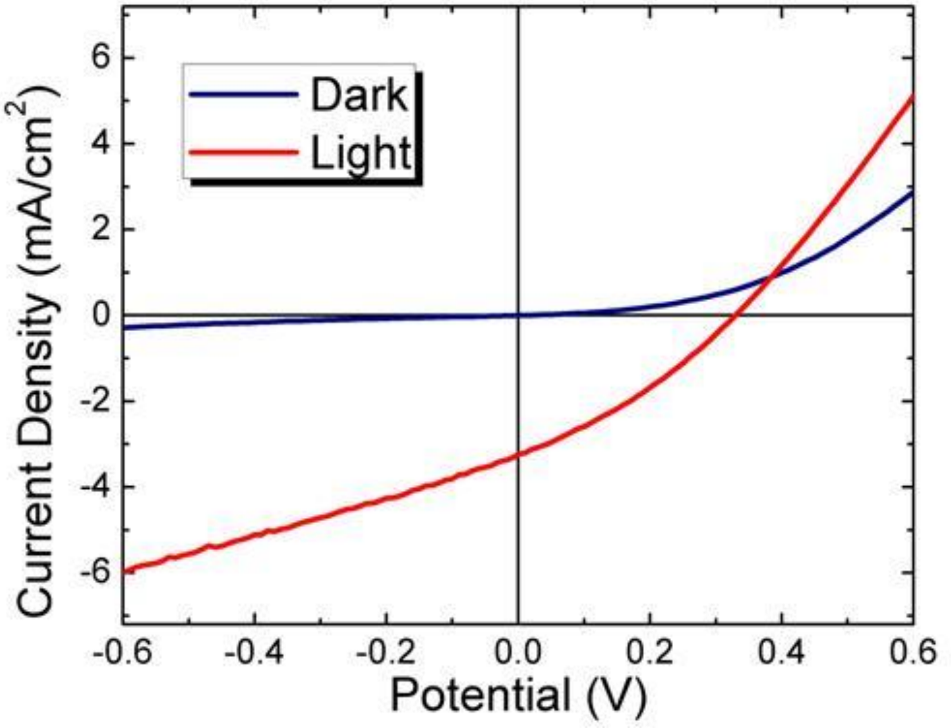
Nanocrystal Film Formation

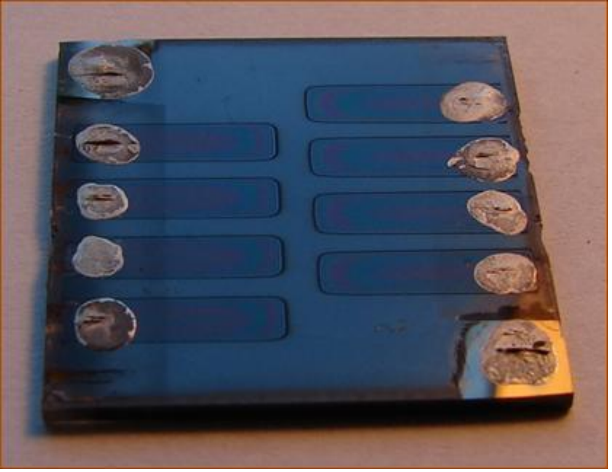
For the solar cell, need uniform films of nanocrystals.



· Standard Cell

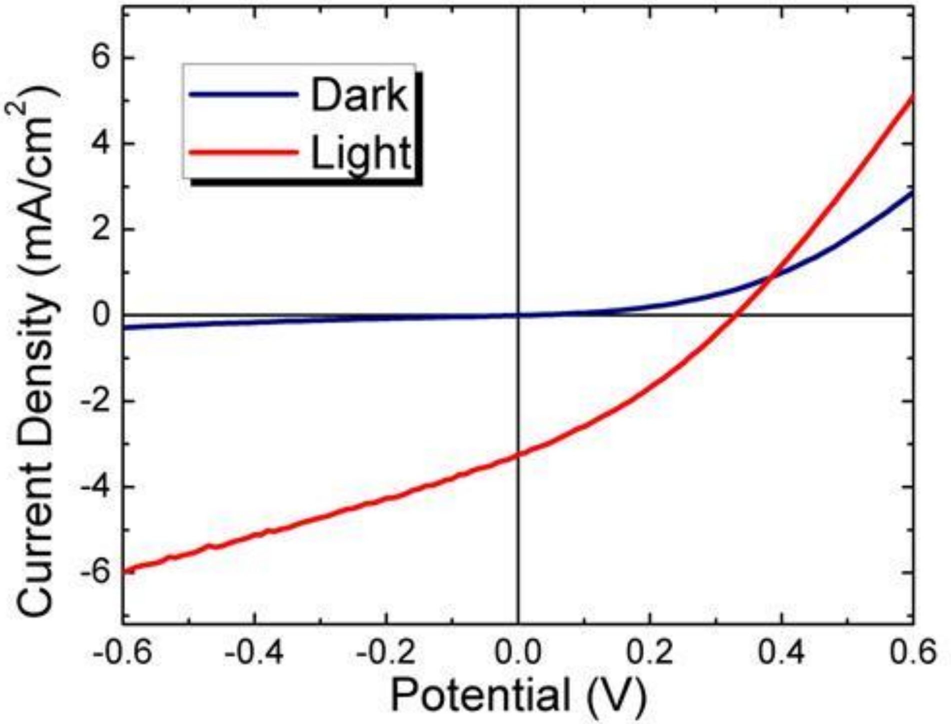
Efficiency	0.341%
V_{oc}	329 mV
J_{sc}	3.26 mA/cm^2
Fill Factor	0.318





• Standard Cell

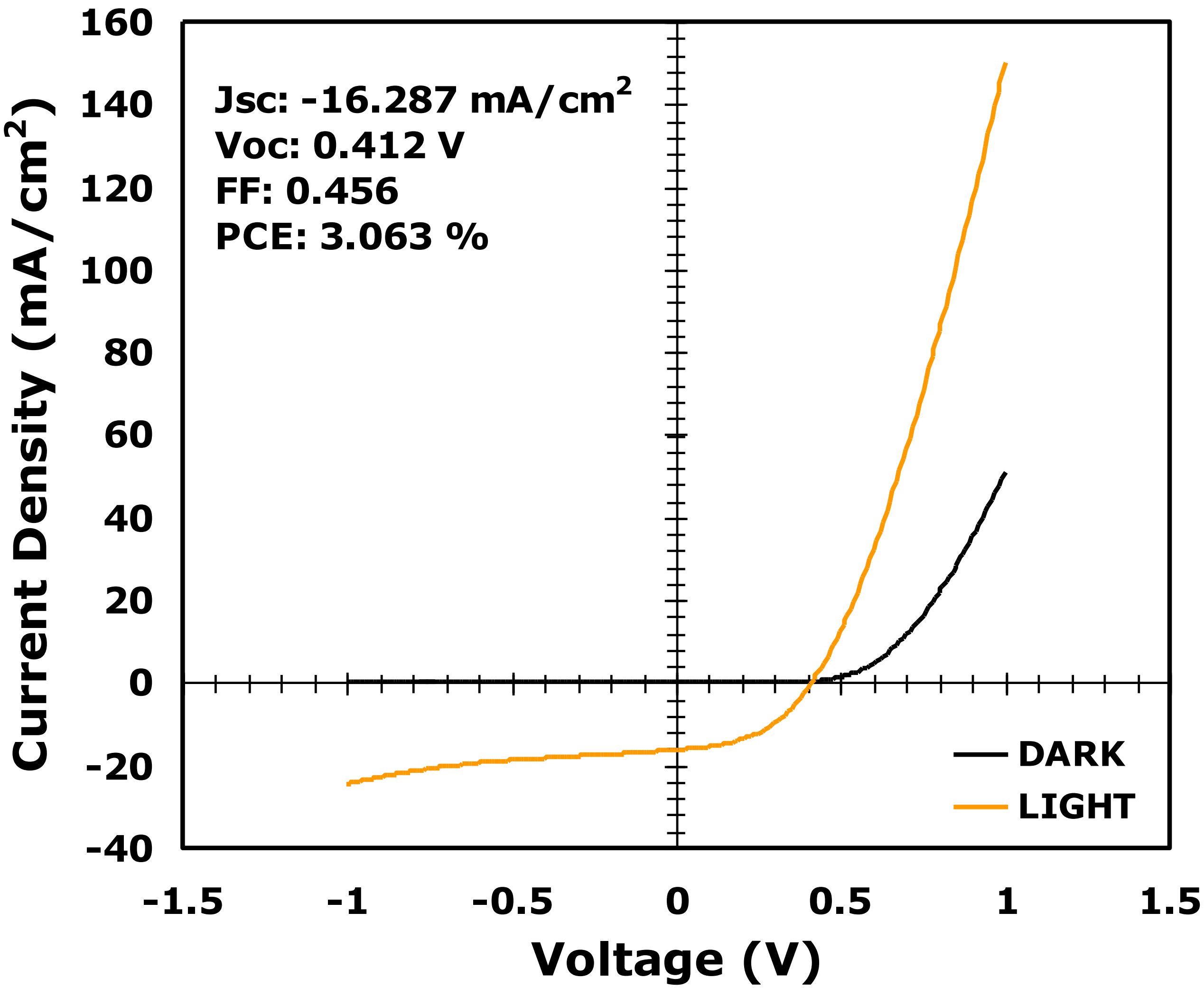
Efficiency	0.341%
V_{oc}	329 mV
J_{sc}	3.26 mA/cm^2
Fill Factor	0.318

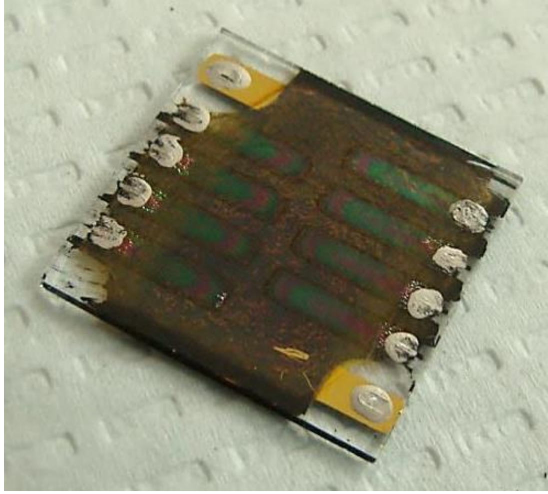


Nanocrystal Film Formation

For the solar cell, need uniform films of nanocrystals.

CIS Nanocrystal PV device





Efficiency of 3.1%

V. A. Akhavan, M. G. Panthani, B. W. Goodfellow, D. K. Reid, B. A. Korgel, "Thickness-limited performance of CuInSe2 nanocrystal photovoltaic devices," *Optics Express,* 18 (2010) A411-A420.

Energy Environ. Sci., 2010, 3, 1600–1606

PAPER www.rsc.org/ees | Energy & Environmental Science

Spray-deposited $CuInSe_2$ nanocrystal photovoltaics

Vahid A. Akhavan,[ab] Brian W. Goodfellow,[ab] Matthew G. Panthani,[ab] Dariya K. Reid,[a] Danny J. Hellebusch,[a] Takuji Adachi[bc] and Brian A. Korgel*[ab]

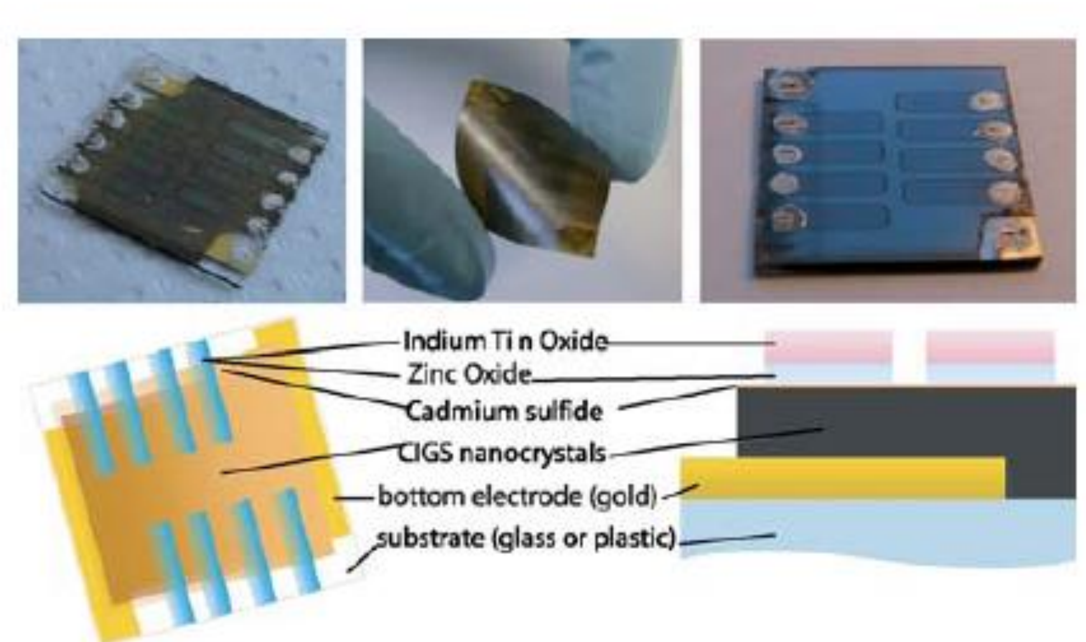
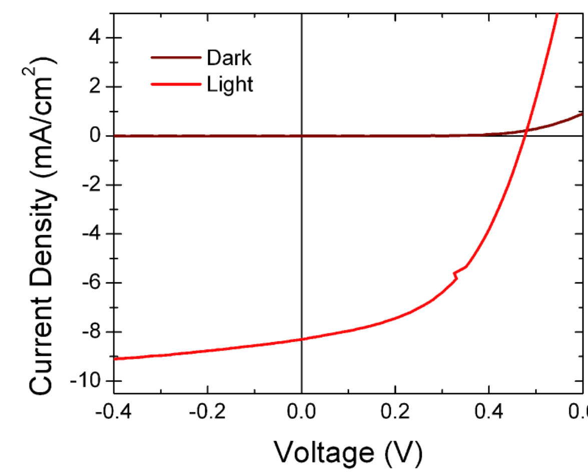


Fig. 3 (Top) Photographs of PVs fabricated by spray-depositing CIS nanocrystals on various substrates: (top left and right) glass and (top, middle) plastic (kapton). (Bottom) Illustration of the device layer structure as viewed from the top and from the side.



Voc = 476 mV
Jsc = 8.3 mA/cm^2
FF = 0.488
η = 1.9%

Efficiency of 2% on plastic

Accomplished to date:

- Solar inks can be chemically synthesized

Accomplished to date:

- Solar inks can be chemically synthesized
- Solar cells can be fabricated with solar inks

Accomplished to date:

- Solar inks can be chemically synthesized

- Solar cells can be fabricated with solar inks

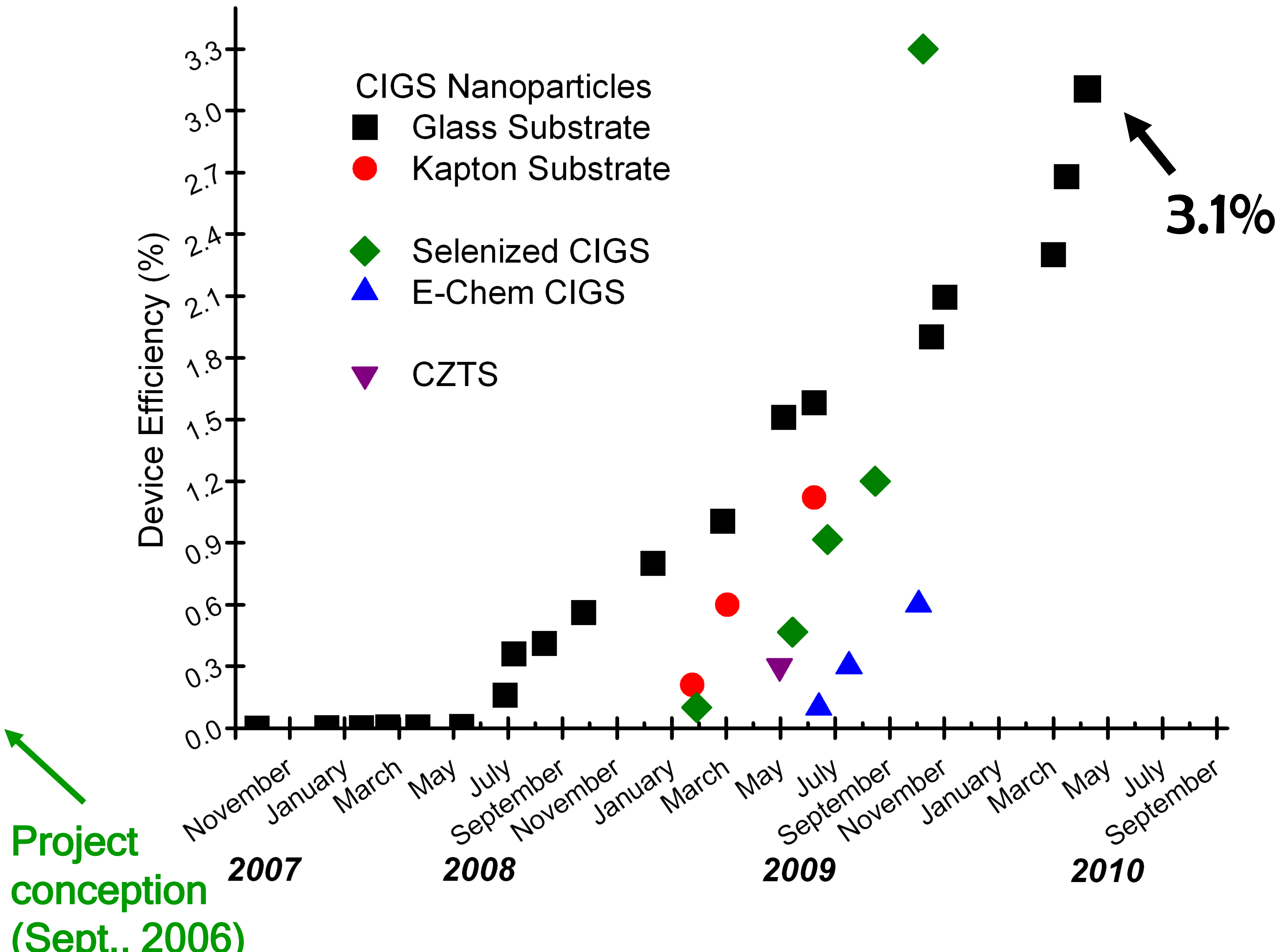
- Solar cells can be fabricated with solar inks on light-weight flexible substrates

Accomplished to date:

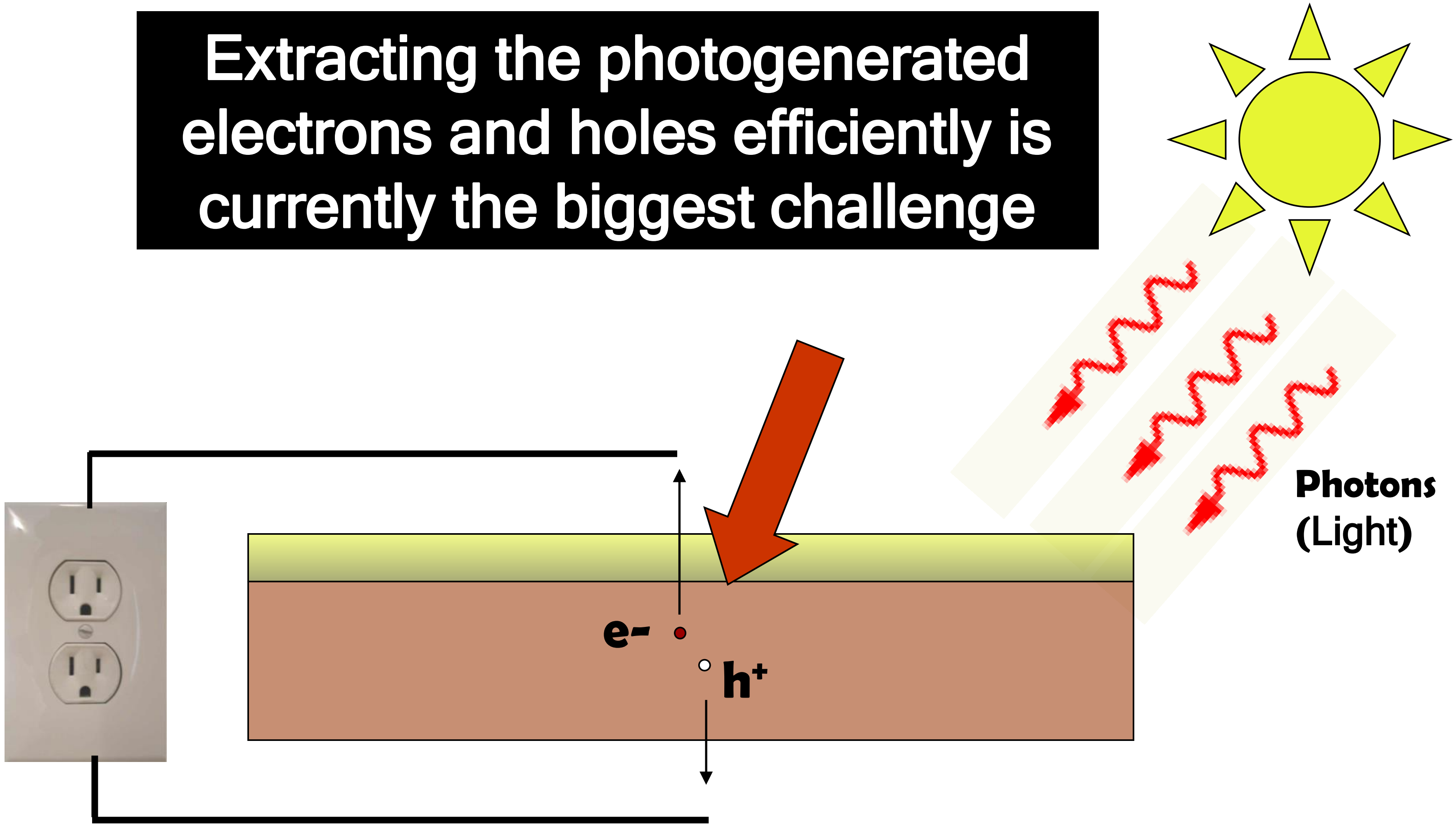
- Solar inks can be chemically synthesized
- Solar cells can be fabricated with solar inks
- Solar cells can be fabricated with solar inks on light-weight flexible substrates

The current challenge is to try to improve the power conversion efficiency up to >10%

Korgel group milestone chart for CIGS Nanocrystal PVs



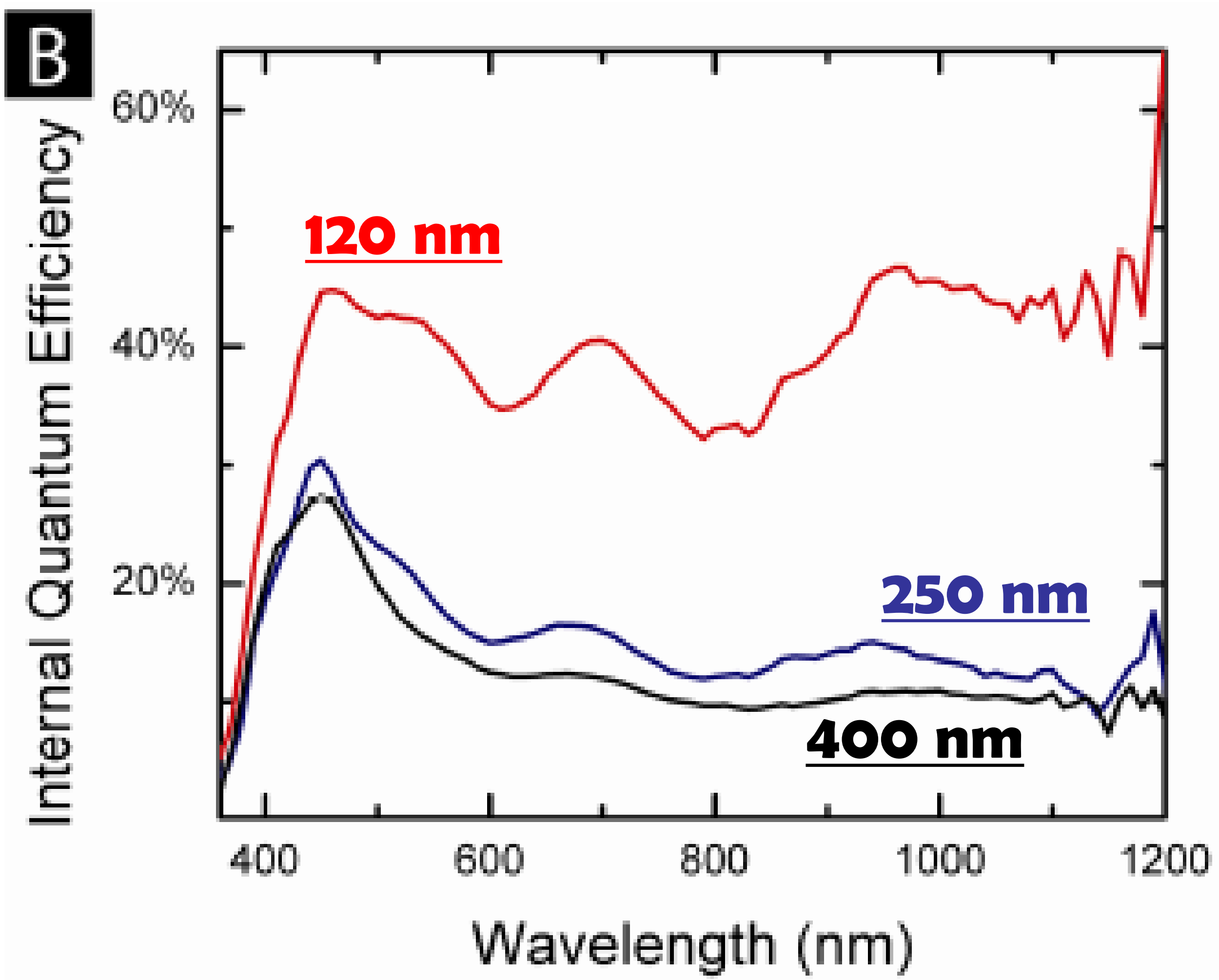
Extracting the photogenerated electrons and holes efficiently is currently the biggest challenge



The highest efficiency devices have very thin nanocrystal layers that do not absorb all of the light

~200 nm thick layer of nanocrystals on glass disc

Thicker nanocrystal layers absorb more light, but are less efficient



V. A. Akhavan, M. G. Panthani, B. W. Goodfellow, D. K. Reid, B. A. Korgel, "Thickness-limited performance of CuInSe2 nanocrystal photovoltaic devices," *Optics Express,* 18 (2010) A411-A420.

Reader's Digest .com

25 Inventions That Will Improve Your Life

Brilliant ideas, inventions, and gadgets for everyday life.

12. Spray-On Solar Panels

While solar panels are hot with homeowners for warming the house and saving electricity, they're often rejected as costly and tricky to install. Now engineers are racing to make a more consumer-friendly version. One attractive candidate is solar ink. Applied with a spray gun, the ink allows builders and homeowners to turn windows, doors, and roofs into power-generating panels. Just spray it on the way you would on a model airplane, says Brian Korgel, the University of Texas at Austin chemical engineering professor who invented the technology. (The ink can also be printed on plastic sheets using an ink-jet-type printer.) He expects the ink to be available in three to five years.

Image 12 of 25 Courtesy University of Texas Cockrell School of Engineering

Reader's Digest .com

25 Inventions That Will Improve Your Life

Brilliant ideas, inventions, and gadgets for everyday life.

12. Spray-On Solar Panels

While solar panels are hot with homeowners for warming the house and saving electricity, they're often rejected as costly and tricky to install. Now engineers are racing to make a more consumer-friendly version. One attractive candidate is solar ink. Applied with a spray gun, the ink allows builders and homeowners to turn windows, doors, and roofs into power-generating panels. Just spray it on the way you would on a model airplane, says Brian Korgel, the University of Texas at Austin chemical engineering professor who invented the technology. (The ink can also be printed on plastic sheets using an ink-jet-type printer.) He expects the ink to be available in three to five years.

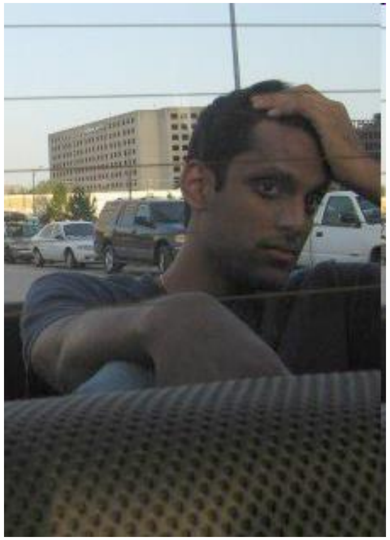
Image 12 of 25 Courtesy University of Texas Cockrell School of Engineering

The challenge is to demonstrate commercially viable efficiencies of >10% (currently, the devices function at 3%)

Special Acknowledgement to:

Vahid Akhavan

Brian Goodfellow



Matt Panthani

Danny Hellebusch

Dariya Reid

Funding from Robert A. Welch Foundation; Air Force Research Laboratory; National Science Foundation

Dr. Brian Korgel

Brian Korgel's research lab studies Nanotechnology, the field of applied science at the atomic and molecular scale. His group focuses on investigating size-tunable material properties, and the self-assembly and fabrication of nanostructures. This multidisciplinary research finds applications in microelectronics, photonics, photovoltaics, spintronics, coatings, sensors and biotechnology.