
An Introduction to Organic Solar Cells

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11th December, 2008

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Outline

□ Motivation

- Need for Energy
- Solar cells
- Organic solar cells

□ Background

- Sun and sunlight spectrum
- Working of p-n junction solar cell
- Operation of organic solar cells

□ The organic solar cells

- Single Layer
- Bilayer Heterojunction
- Bulk Heterojunction

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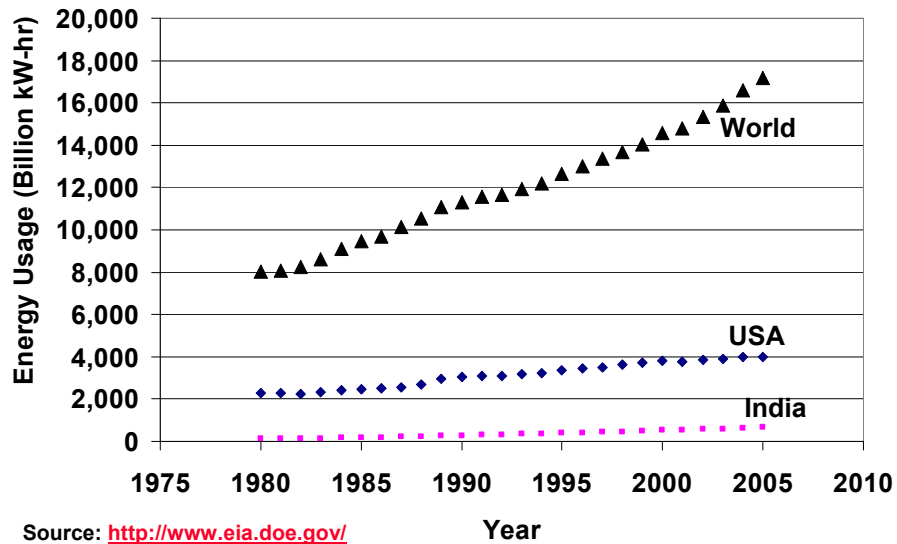
Motivation

- ❑ Need for Energy
- ❑ Solar cells
- ❑ Organic solar cells

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World Energy Usage

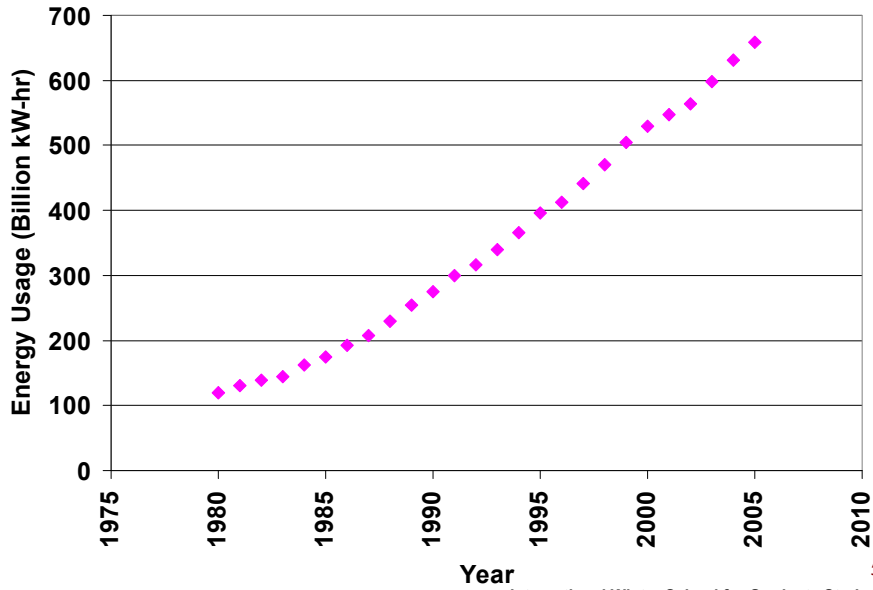


Source: <http://www.eia.doe.gov/>
Energy Information Administration

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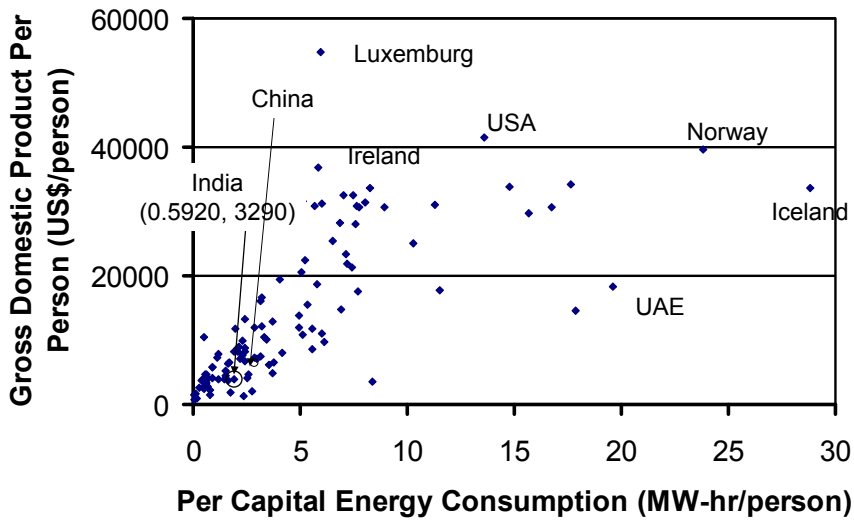
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Energy Usage in India



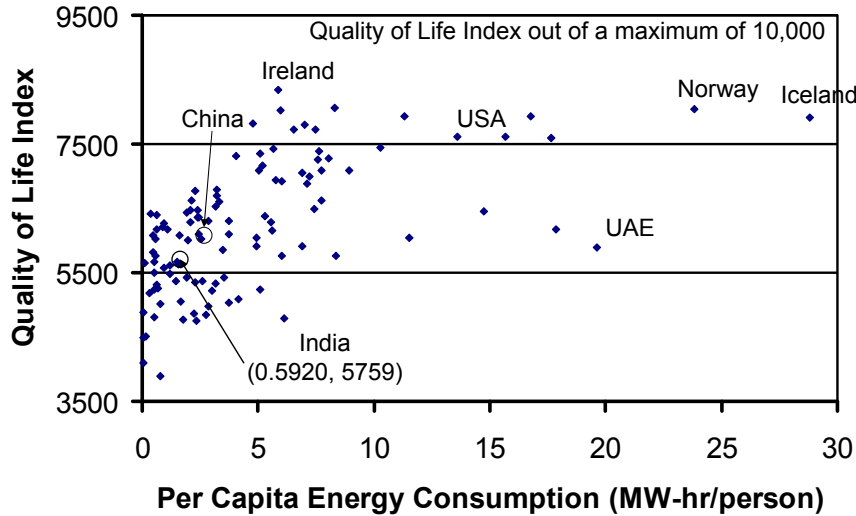
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GDP and Energy Consumption



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Quality of Life and Energy Consumption



www.economist.com/media/pdf/QUALITY_OF_LIFE.pdf

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Generating Energy Needed for Quality of Life

- Fossil and nuclear fuels are costly
 - If we include the environmental cost
- The sun shines on everyone
 - Ideal for distributed power generation and remote locations
- Tap solar energy directly
 - Ideal for distributed power generation
 - More environmentally friendly

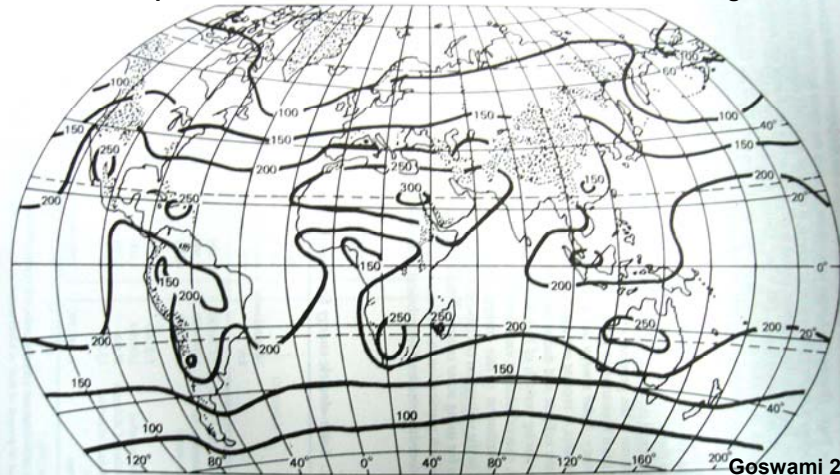
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Annual Mean Global Irradiance

On a horizontal plane at the surface of the earth

W m^{-2} averaged over 24 h



With 10% efficient solar cell area of solar cell needed in 2004

USA: 330 km × 330 km (2.64% area); India 60 km × 60 km (0.12% area)

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History

- ❑ 1839 Photovoltaic effect discovered by Edmond Becquerel
- ❑ 1954 First Silicon Solar Cell Bell Lab by Chapin, Fuller and Pearson ($\eta \sim 6\%$)
- ❑ 1970s Surge in research to harness solar energy
- ❑ 1986 Heterojunction Organic Solar Cell by Tang of Eastman Kodak
- ❑ 2007 Highest efficiency solar cells with $\eta \sim 40.7\%$ in Spectrolab
- ❑ A big surge in solar cells research & development is underway
- ❑ 2007 Highest efficiency organic solar cells ($\eta \sim 5.7\%$)

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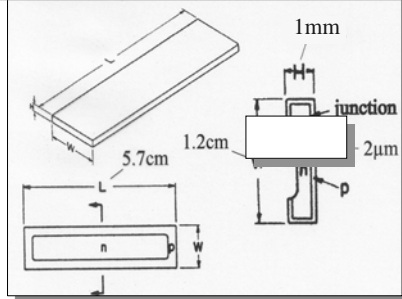
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The Birth of Silicon Photovoltaics

A New Silicon *p-n* Junction Photocell for Converting Solar Radiation into Electrical Power

D. M. CHAPIN, C. S. FULLER, AND G. L. PEARSON
 Bell Telephone Laboratories, Inc., Murray Hill, New Jersey
 (Received January 11, 1954)

Efficiency $\eta \approx 6\%$

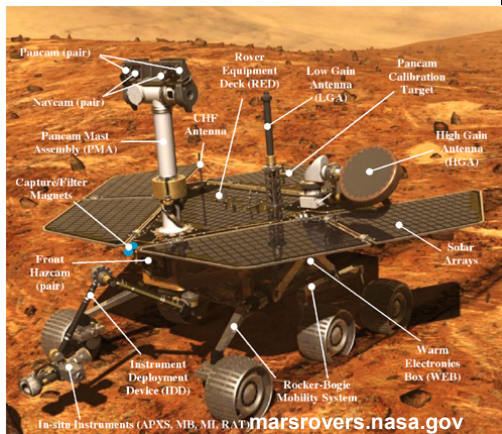


Chapin *et al.* 1954

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Space Applications



Photovoltaics are the mainstay

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Remote Locations



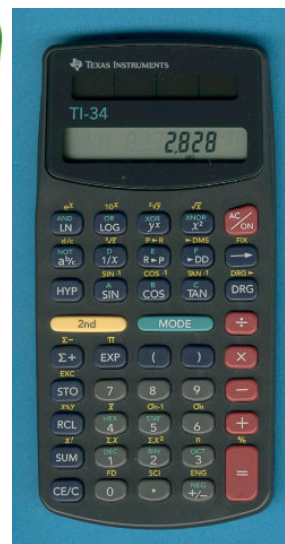
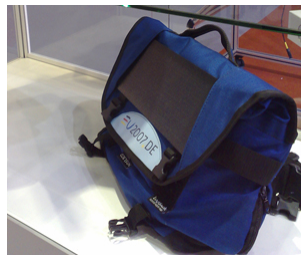
Photovoltaics
are attractive



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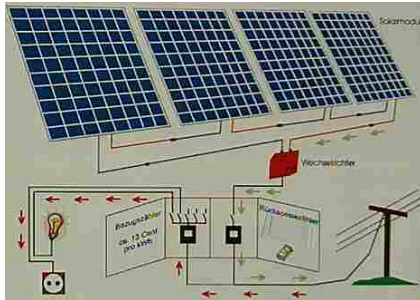
Consumer Electronics



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Grid Supply



www.sun-consult.de

Need to make photovoltaics attractive in the marketplace



www.e2tac.org

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Solar Energy Usage and Pricing

	Solar markets (average of last 5 years)	Solar Price/Competing Energy source
Remote Industrial	17%	0.1-0.5 times
Remote Habitation	22%	0.2-0.8 times
Grid Connected	59%	2-5 times
Consumer Indoor	2%	n/a

Solar Energy: 30 c (Rs. 12) per kWh

Need to lower cost to 10c (Rs.4) per kWh and below

<http://www.solarbuzz.com/StatsCosts.htm> (2006 data; accessed 11.12.2008) 16

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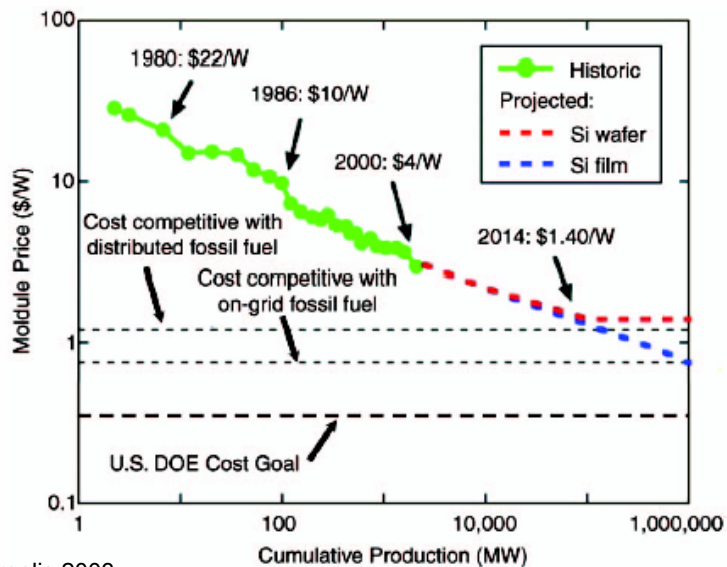
Electricity Generation Cost (Per kWh)

Energy Source	Cost
Combined cycle gas turbine	3 ¢ -5 ¢ (Rs.1.20-Rs.2.00)
Wind	4 ¢ -7 ¢ (Rs.1.60-Rs.2.80)
Biomass gasification	7 ¢ -9 ¢ (Rs.2.80-Rs.3.60)
Remote diesel generation	20 ¢ -40 ¢ (Rs.8.00-Rs.16.00)
Solar PV central station	20 ¢ -30 ¢ (Rs.8.00-Rs.12.00)
Solar PV Distributed	20 ¢ -50 ¢ (Rs.8.00-Rs.20.00)

<http://www.solarbuzz.com/StatsCosts.htm> (2006 data; accessed 11.12.2008) 17

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Solar Energy Production and Price

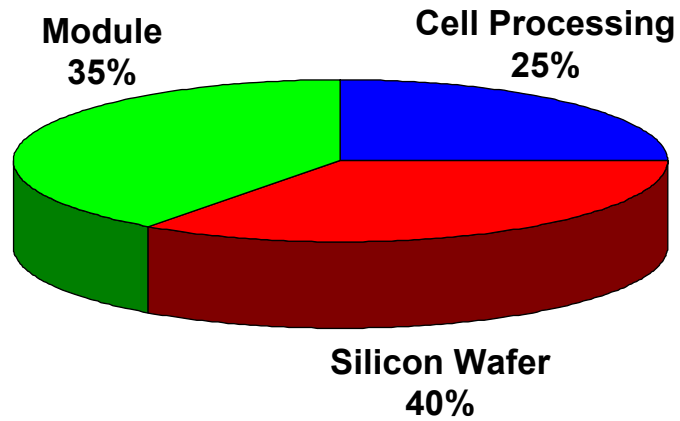


R.M. Margolis 2003

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Cost Breakdown of Silicon Photovoltaics



Data from A. Rohatgi

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Lowering Cost of Solar Cells

□ Thin Film Solar Cells

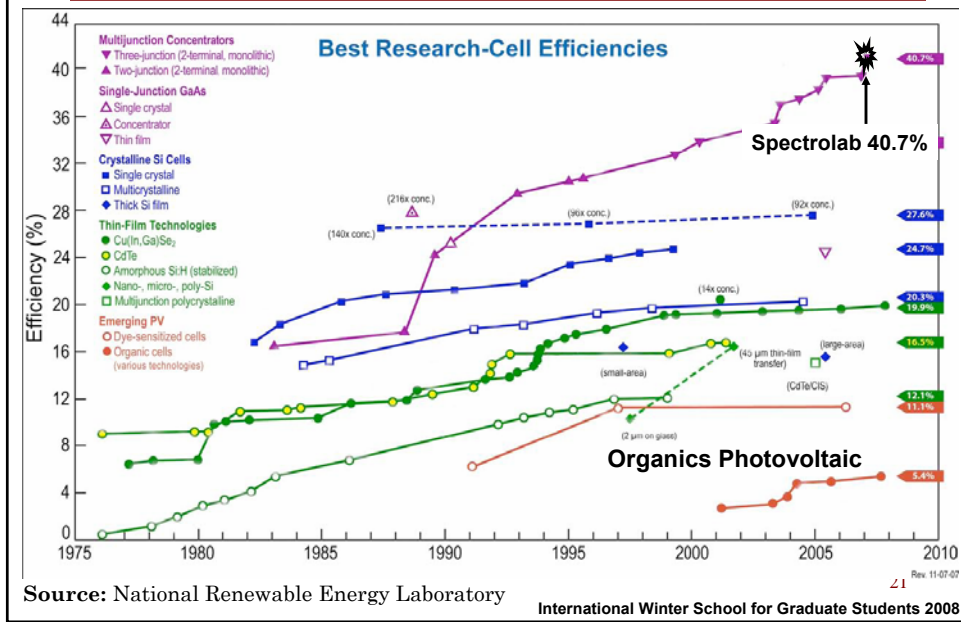
- Multiple junction solar cells ($a\text{-Si:H}$, $a\text{-SiGe:H}$)
- CdTe based cells (CdTe , CdS)
- CuInSe_2 (CIS) Ternary & Multinary compound solar cells
- Multicrystalline/Microcrystalline silicon solar cells
- Thin film GaAs solar cells
- Organic solar cells

S. Deb 2004

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Efficiency of PV for Different Materials



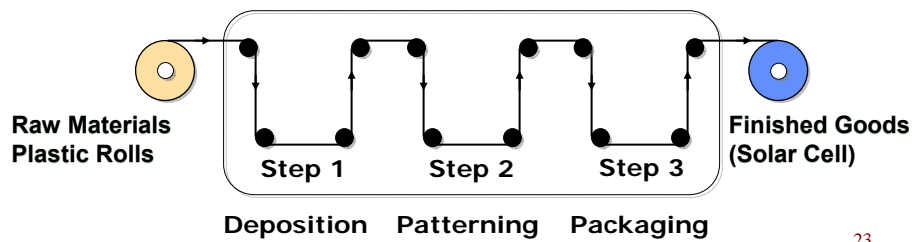
Why Organic Solar Cells?

High-Throughput and Low-Cost Processing

- Printing
 - Screen Printing
 - Stamping
- Spraying
- Spin Coating
- Vaporisation

Roll-To-Roll

A simplified overview



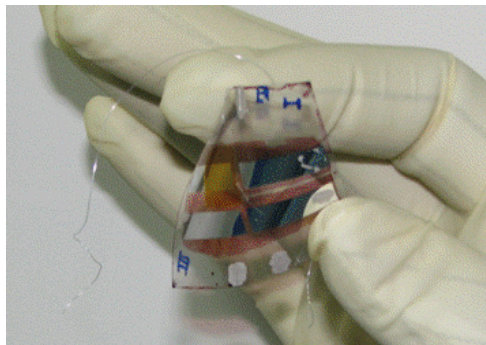
www.rolltronics.com

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Flexible Solar Cells

- Flexible Surfaces
- Conformal Surfaces



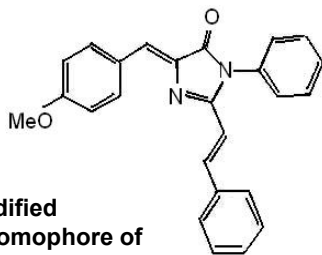
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Eco-Friendly Technology

- ❑ Appropriate Process
 - Ink jet printing uses material only where needed

- ❑ Biodegradable Molecule



Modified chromophore of Green Fluorescent Protein Molecule



Anode contacts

Cathode contacts

Solar cell device using the molecule

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Background

- ❑ Sun and sunlight spectrum
- ❑ Working of *p-n* junction solar cell
- ❑ Operation of organic solar cells

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The Sun

- ❑ Distance of 149.6×10^9 m from earth
- ❑ Age: 4.5×10^9 years old
- ❑ Expected to last $\sim 5 \times 10^9$ years
- ❑ Energy produced by fusion of H into He
- ❑ 700×10^9 kg s^{-1} H consumed
- ❑ 695×10^9 kg s^{-1} He formed
- ❑ 386×10^{18} MW energy output
- ❑ Core temperature 15.6×10^6 K
- ❑ Surface temperature 5760 K

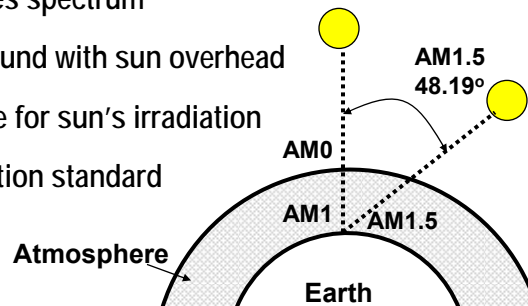
NASA web-site

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Energy Reaching Earth

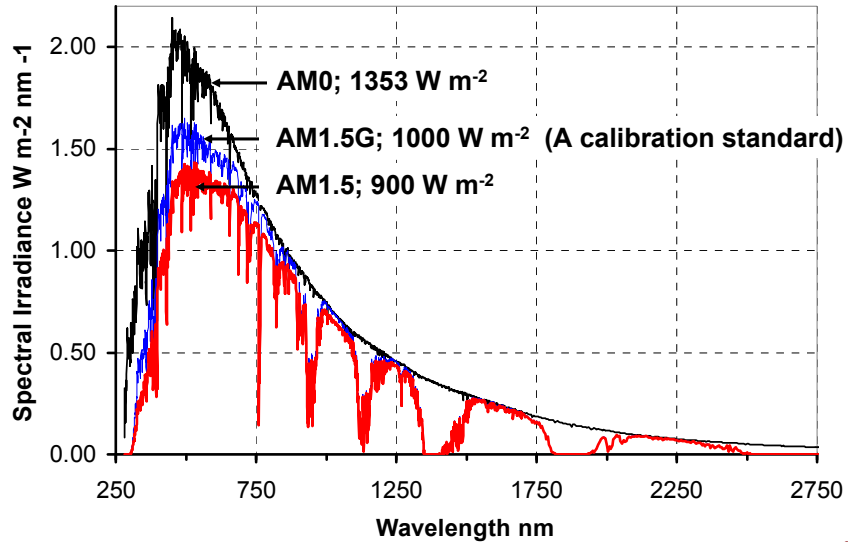
- ❑ From earth sun's rays appear parallel
- ❑ Spectrum of sunlight just outside atmosphere Air Mass 0 (AM0)
 - Sun could be modelled as black body radiation
- ❑ The atmosphere modifies spectrum
- ❑ AM1 is spectrum on ground with sun overhead
- ❑ AM1.5 is a good average for sun's irradiation
- ❑ AM1.5G used as calibration standard



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The Solar Spectrum

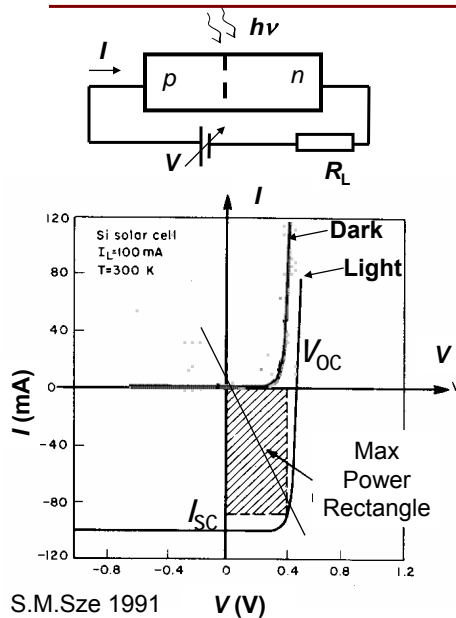


Data from National Renewable Energy Laboratory, Golden, Colorado, USA

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Efficiency of a Solar Cell



S.M.Sze 1991

V (V)

- Fill Factor FF is the ratio of area of maximum rectangle fitted in the 4th quadrant I - V and the product of V_{OC} and I_{SC}

- Maximum Power Output

$$P_{max} = V_{OC} \times I_{SC} \times FF$$

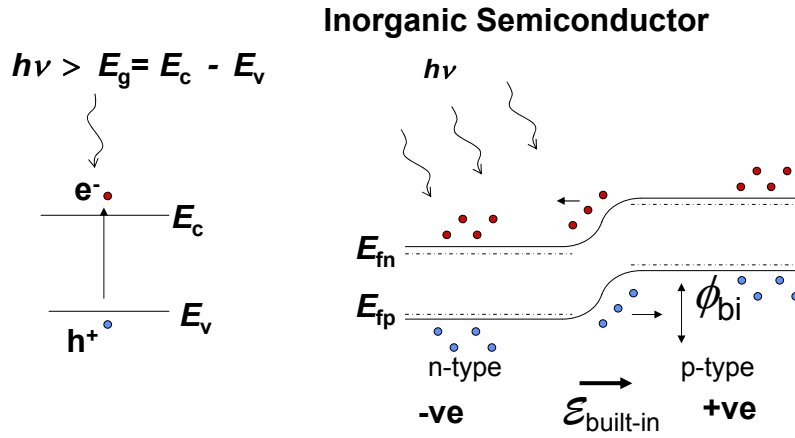
- Efficiency

$$\eta = \frac{P_{max}}{\text{Incident Optical Power}}$$

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Classic *p-n* Junction Photovoltaic Cell

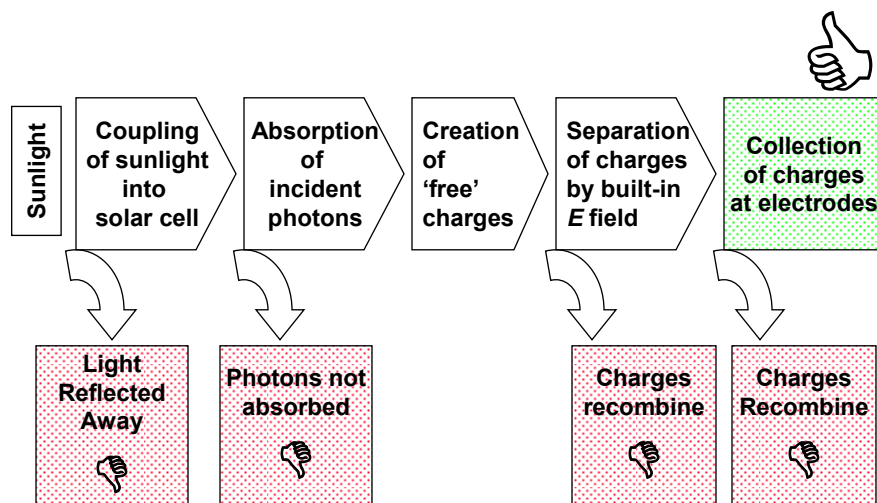


- Incident photon immediately forms mobile electrons and holes

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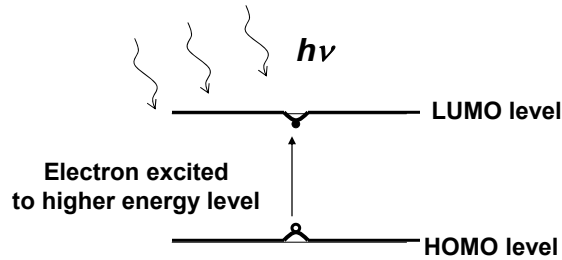
Photovoltaic Process In Solar Cells



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Exciton Formation

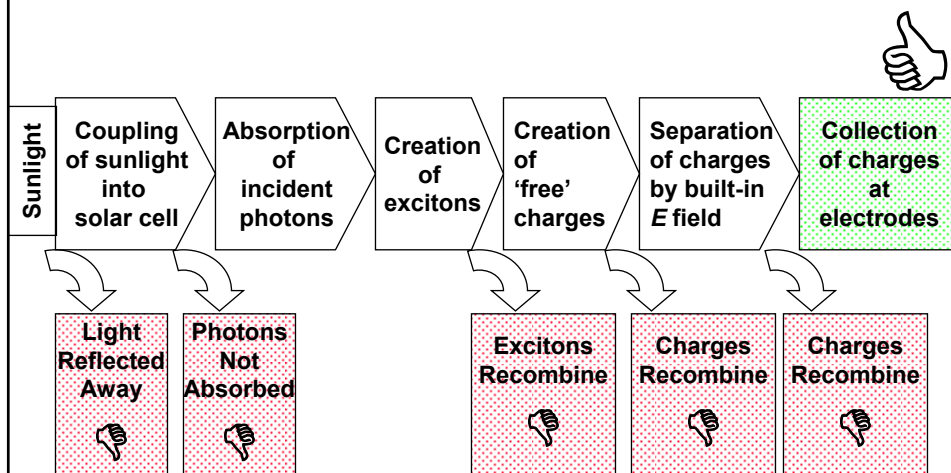


- ❑ Absorbed photon creates an *exciton*
- ❑ Excitons do NOT always form free electrons and holes
 - This is especially true in organic semiconductors
 - Here, strong fields are needed to dissociate excitons

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Photovoltaic Process In Organic Solar Cells



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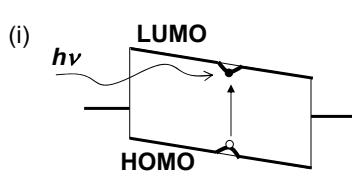
The Organic Solar Cell

- ❑ Single Layer
- ❑ Bilayer Heterojunction
- ❑ Bulk Heterojunction

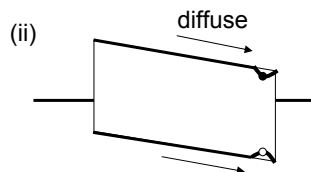
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Single Layer Organic Solar Cells

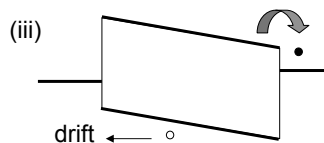


• Generation of exciton



• Diffusion of exciton towards electrodes

⊖ Annihilation of exciton during diffusion



• Splitting of exciton at interface

• Collection of charge in respective electrodes

⊖ Recombination of exciton at metal interface

⊖ Recombination of free electron/hole

**Single layer devices efficiencies low!
How to minimise the losses?**

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First Bi-layer Organic Solar Cell

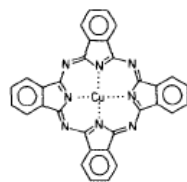
Two-layer organic photovoltaic cell

C. W. Tang

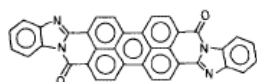
Research Laboratories, Eastman Kodak Company, Rochester, New York 14650

(Received 28 August 1985; accepted for publication 31 October 1985)

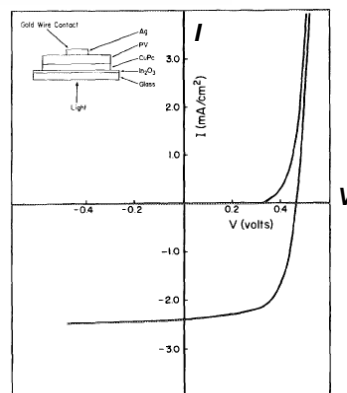
Copper phthalocyanine and
perylene tetracarboxylic derivative layers
Efficiency of ~1%, FF=0.65



CuPc



PV

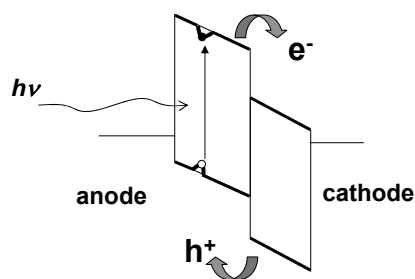


C.W. Tang, 1986

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Hetero-junction Organic Solar Cells



Bi-layer or hetero-junction structure

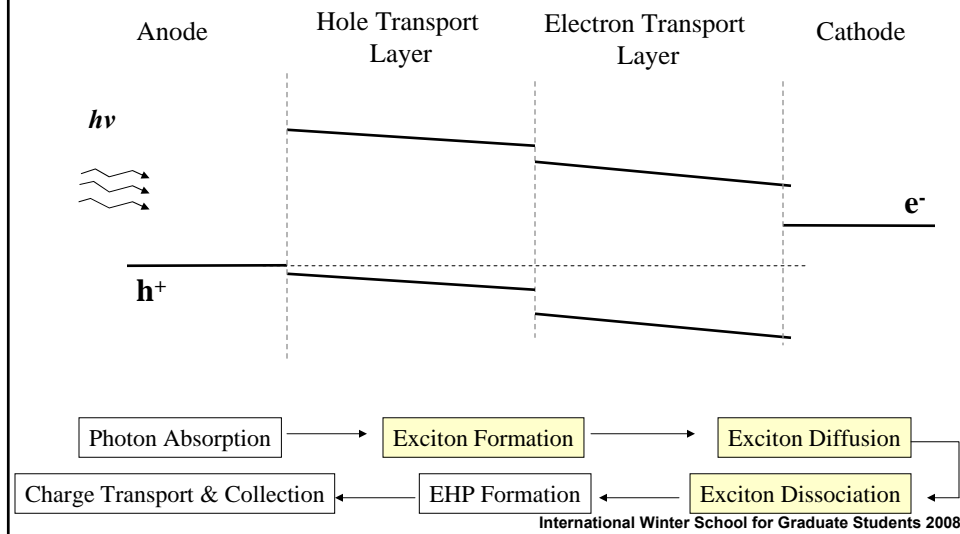
- ❑ Exciton separation away from metal interfaces
- ❑ Hence higher efficiency of charge transfer

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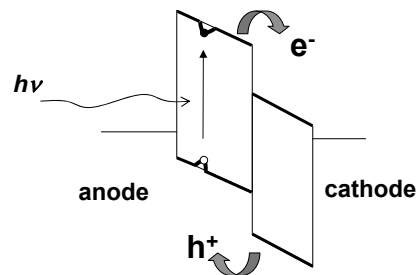
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Organic Solar Cells Operation

A Heterojunction Organic Solar Cell Structure



Effect of Layer Thickness

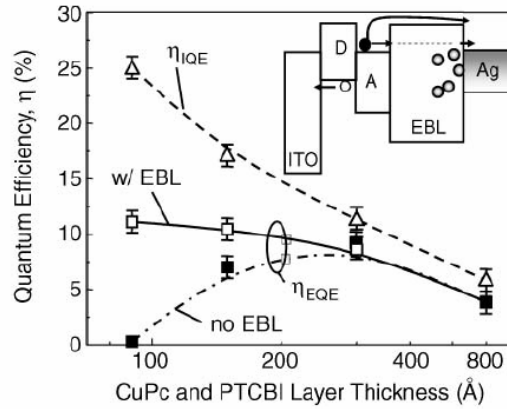


- Varying layer thickness has a trade off between
 - light absorbed & excitons reaching bilayer junction
 - exciton/free charge recombination & charge transport
- Use electron blocking layer
- Use bulk-heterojunctions

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Effect of Exciton Blocking Layer (EBL)

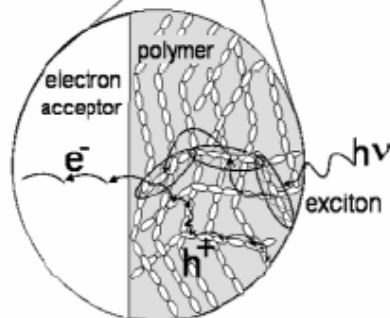
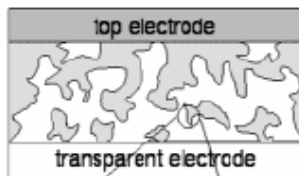


- Metal interface effects are screened by EBL
- EBL Helps achieve higher light absorption near interface

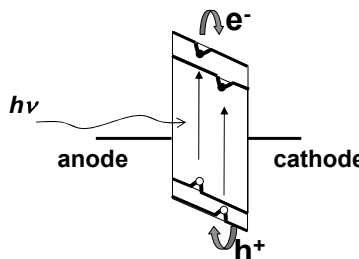
P. Peumans *et al.* 2000

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Bulk Hetero-junction Organic Solar Cells



- If exciton won't come to junction, take junction to exciton
- Blend of acceptor and donor
 - polymer + C_{60} /CNT popular
- η_{ED} improves; η_{CC} can decrease



Bulk/Dispersed /Graded Heterojunction solar cell

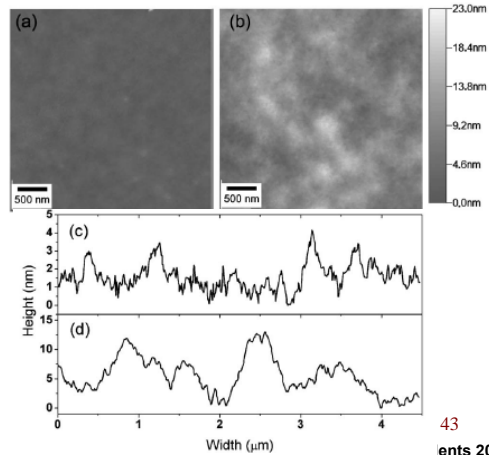
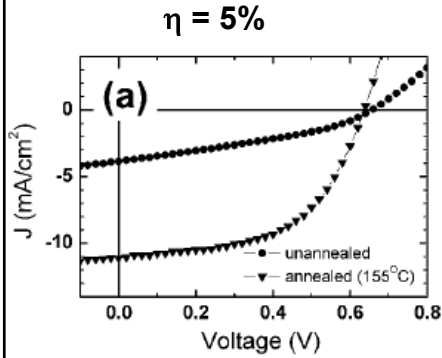
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Blend Heterostructure Device – best today

High-efficiency photovoltaic devices based on annealed poly(3-hexylthiophene) and 1-(3-methoxycarbonyl)-propyl-1-phenyl-(6,6)C₆₁ blends

Marisol Reyes-Reyes, Kyungkon Kim, and David L. Carroll^{a)}
The Center for Nanotechnology and Molecular Materials, Department of Physics, Wake Forest University,

APL 87, 083506 (2005)



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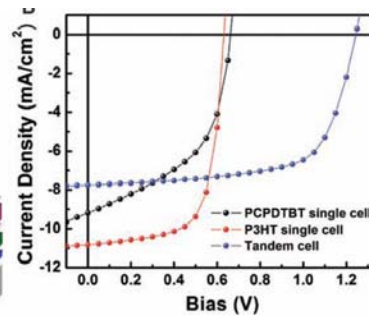
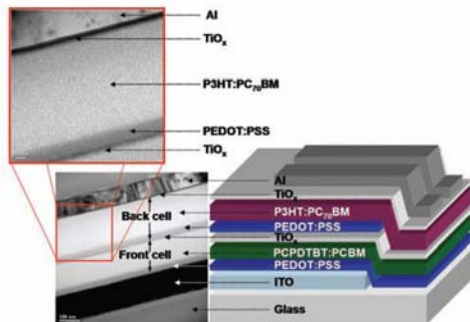
Highest Efficiency Reported OSC Till Date

www.sciencemag.org **SCIENCE** VOL 317 13 JULY 2007 pp. 223-225

Efficient Tandem Polymer Solar Cells Fabricated by All-Solution Processing

Jin Young Kim,^{1,2} Kwanghee Lee,^{1,2*} Nelson E. Coates,¹ Daniel Moses,¹
 Thuc-Quyen Nguyen,¹ Mark Dante,¹ Alan J. Heeger¹

Tandem Cell: $J_{sc} = 7.8 \text{ mA cm}^{-2}$, $V_{oc} = 1.24 \text{ V}$, $FF = 0.67$ and $\eta = 6.5\%$



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Summary

- ❑ Solar cells are imperative for sustainable development
- ❑ Organic solar cells a potential solution to energy problems
- ❑ Exciton dissociation the key difference in organic solar cells
- ❑ Organic solar cells has progressively evolved from
 - Single layer homojunctions
 - Bilayer heterojunctions
 - Bulk heterojunctions

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