Photodetectors and solar cells

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(12/03/2009)

Outlines

- Introduction

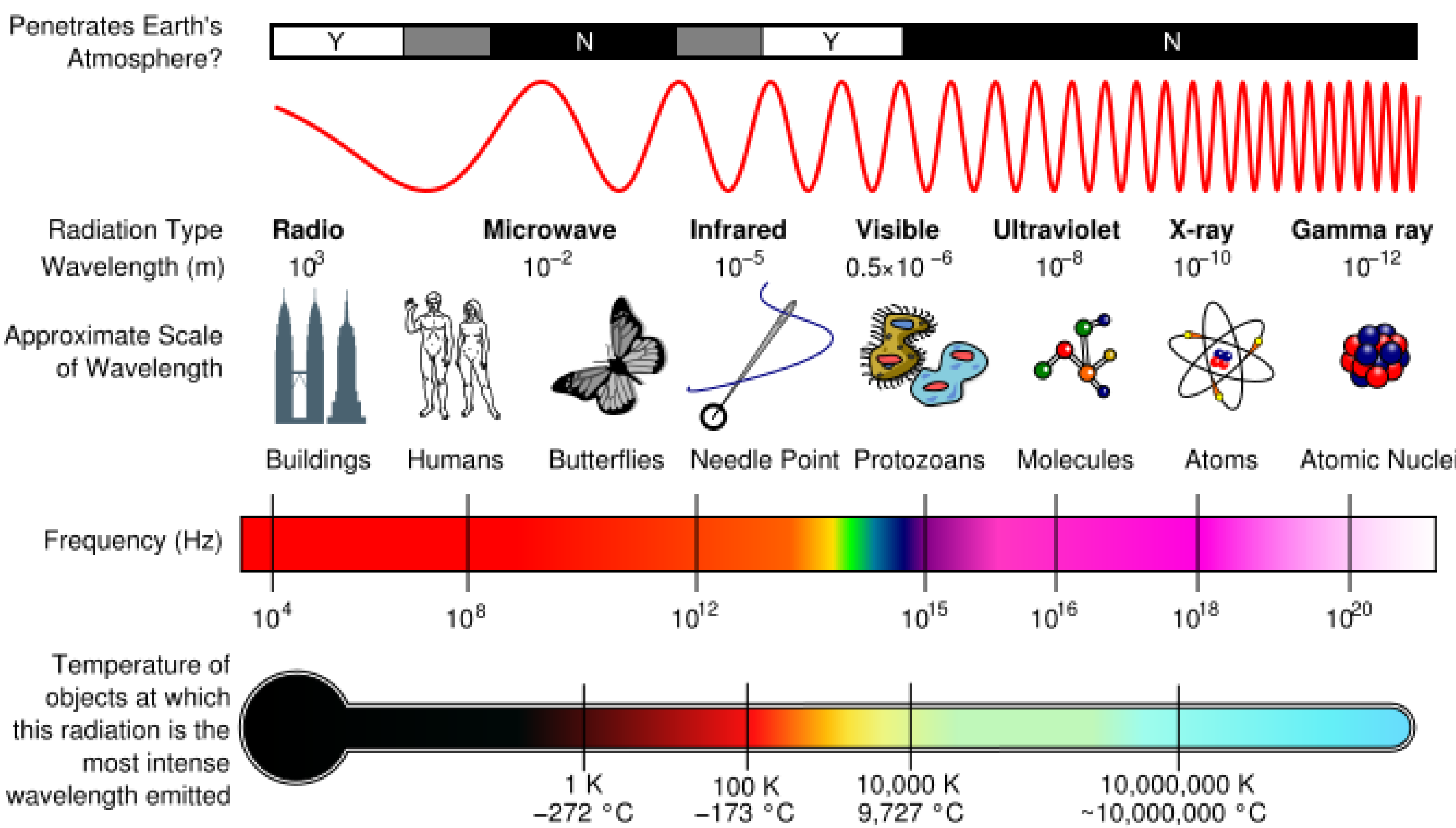
- Photodiodes

  - photoconductive
  - photovoltaic
  - MSM photodiodes
  - avalanche photodiodes

- Noise in photodetectors

- Solar cells

Introduction



http://en.wikipedia.org

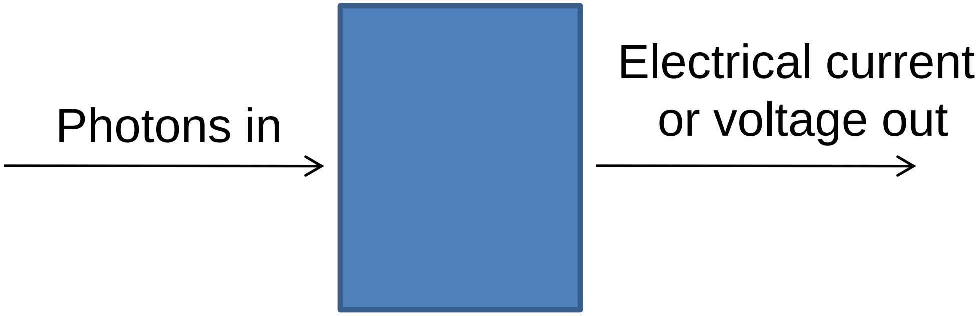
Types of photodetectors

- PIN Photodiodes
- Metal–Semiconductor–Metal Photodetectors
- Avalanche photodiodes
- Photomultipliers
- Photoresistors
- Thermal detectors
- Pyroelectric photodetectors
- …

What photodetectors really do?

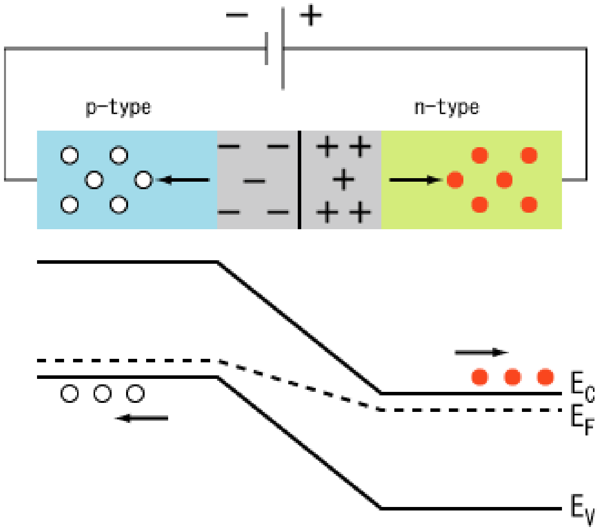
What photodetectors really do?

Transform photon energy into electrical current or voltage

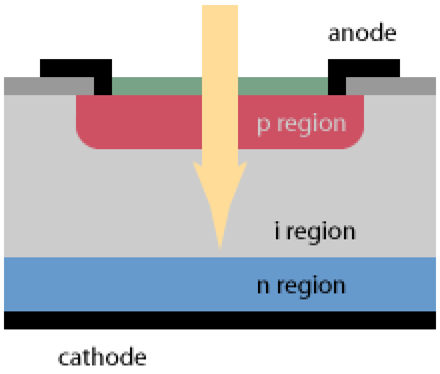


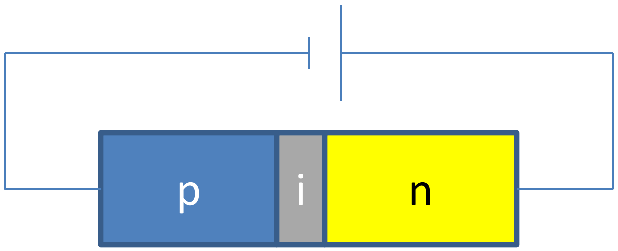
PIN photodiode

Reverse biased p-n junction

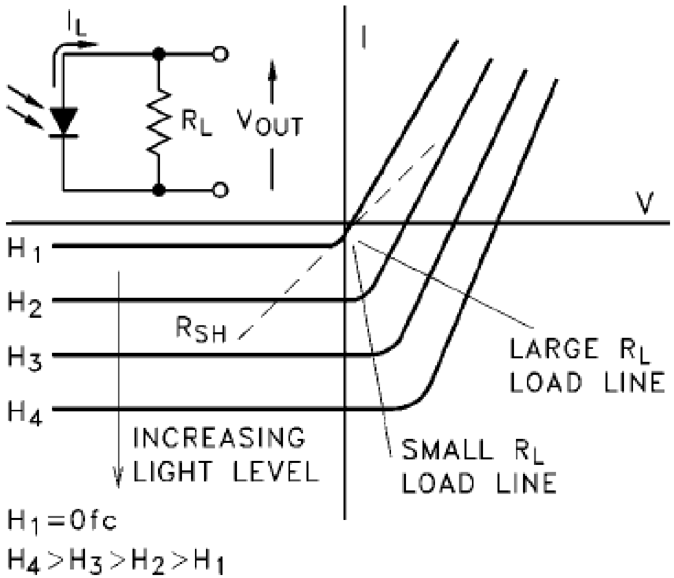


p-i-n photodiode

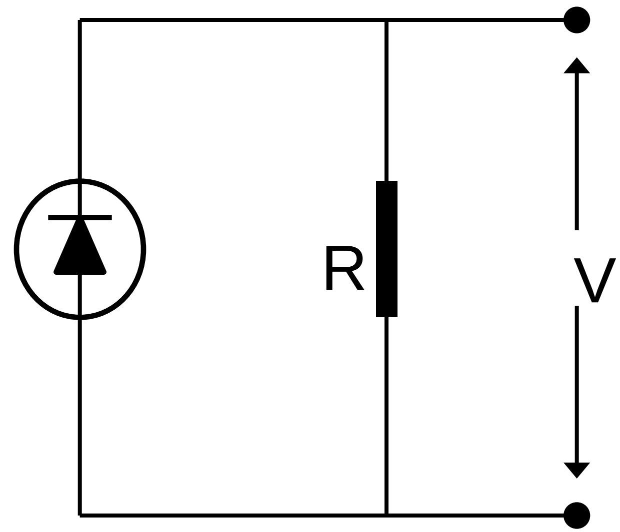




Photovoltaic mode



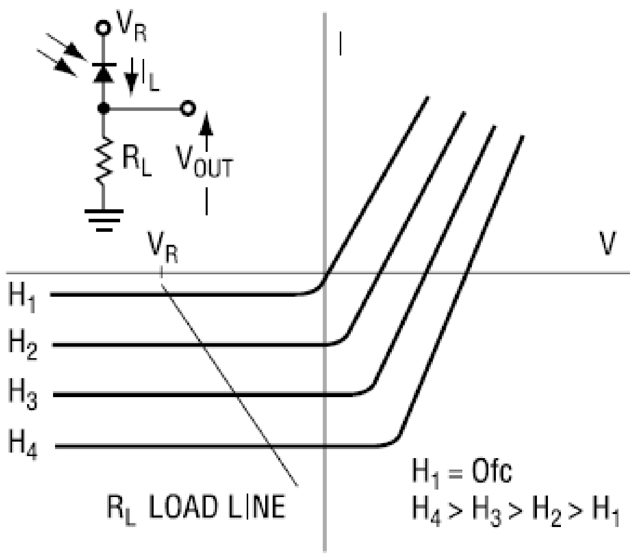
Current/Voltage Characteristics - Photovoltaic Mode



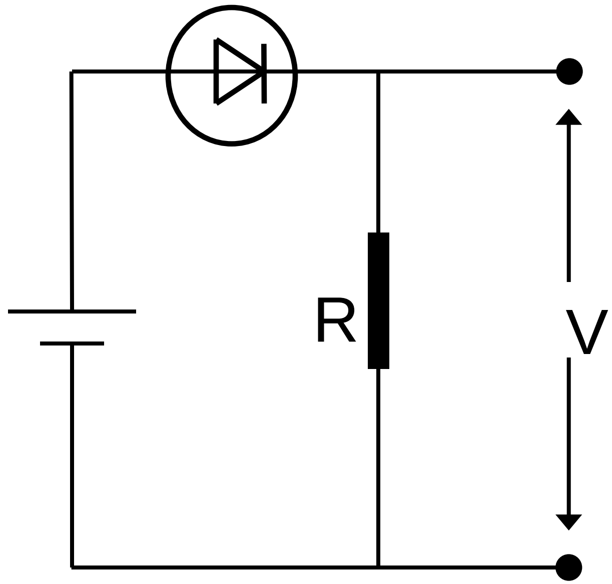
Advantages: Low noise, no power supply

Disadvantages: Nonlinear response, low speed

Photoconductive mode



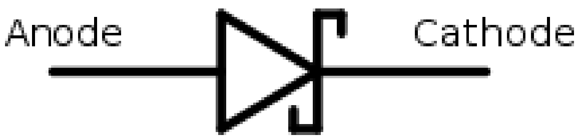
Current/Voltage Characteristics - Photoconductive Mode



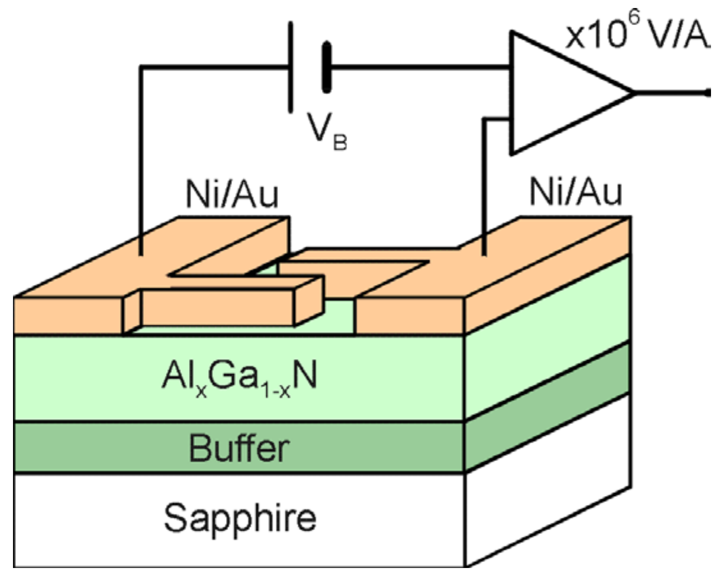
Disadvantages: larger noise, need power supply

Advantages: linear response, faster speed

Metal–Semiconductor–Metal Photodetectors



Schottky Junction



Advantage: Very large operating bandwidth, >> 1GHz

Avalanche photodiodes

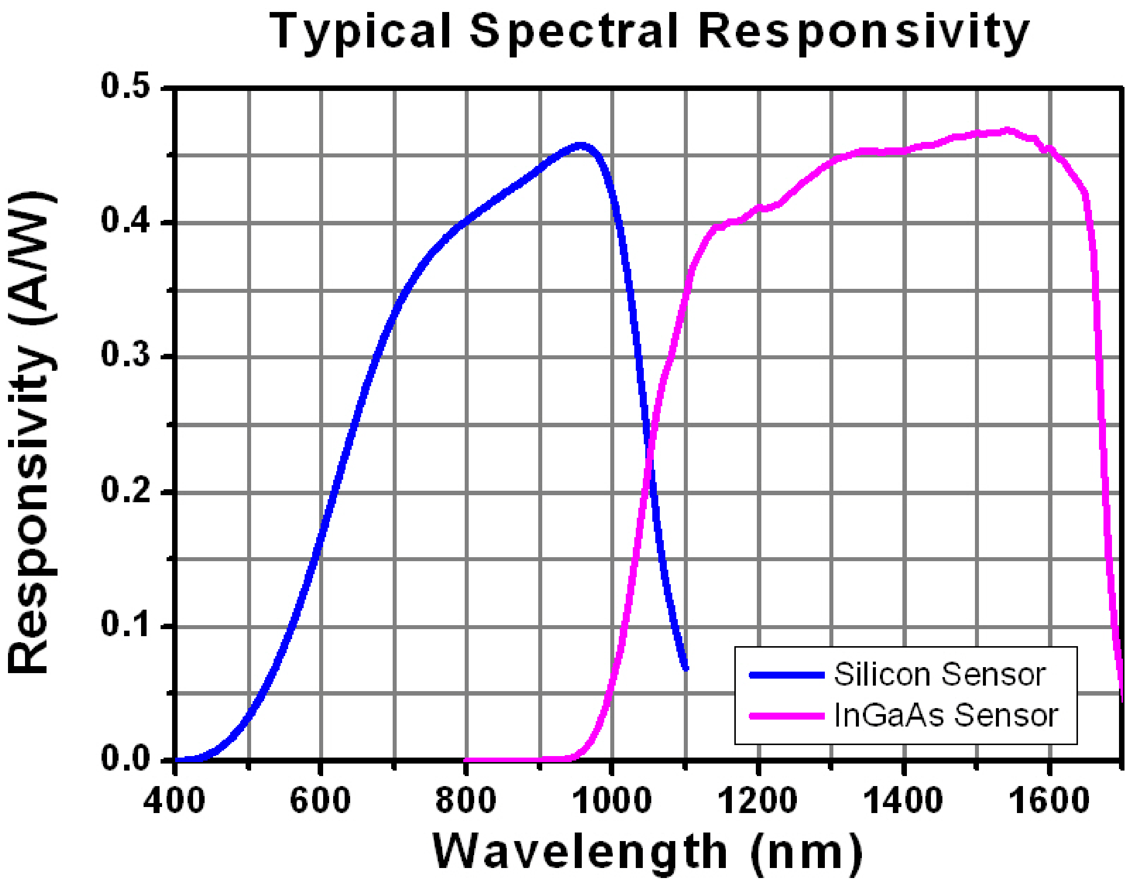
High biased voltage ~100V

Avalanche effect

Large gain factor: 10-1000 times

Can do photon counting

Spectral response



Noise in photodetectors

There are three main types of noise in photodetectors:

1. Shot noise

2. Dark current

3. Thermal noise

Shot noise

Shots noise

Shot noise or *quantum noise* arises from the statistical nature of the production and collection of photoelectrons when an optical signal is incident on a photodetector:

$$\langle i_S^2 \rangle = 2qI_p B \langle M \rangle^2 F_A$$

B – receiver bandwidth

I_p – Photo current

F_A – noise figure associated with the random nature of avalanche process $\approx M^x$ where depends on material.

For pin photodetector, M and F_A equal to 1.

Dark current noise

Dark-current noise

Photodiode dark current is current that continues to flow through the bias circuit of the device when no light is incident on the photodiode. It arises from electrons and/or holes which are thermally generated in the pn junction of the photodiode.

$$\langle i_D^2 \rangle = 2qI_D B \langle M \rangle^2 F_A$$

Thermal noise

Thermal noise

It is contributed by the receiver circuit.

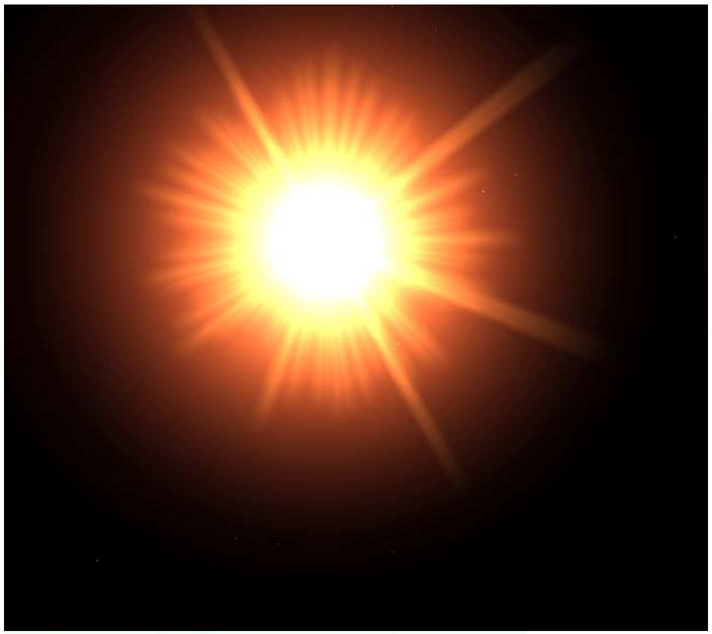
$$\langle i_T^2 \rangle = \frac{4k_B T}{R_{eq}} B$$

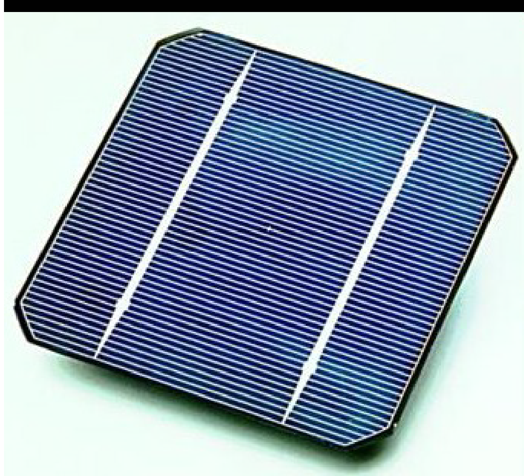
Understanding photodetector specifications

Specification Table

Part#	Material	Spectral Range (nm)	Active Area	Diode Package Type**	Rise/(Fall) Time* $R_L = 50\Omega$	NEP ($W/Hz^{1/2}$)	Typical Dark Current	Junction Capacitance*
FGA04†	InGaAs	800-1800	0.008 mm^2 (Ø0.1 mm)	TO-46 w/ FC/PC Connector	100 ps (100 ps) @ 5 V	1.5×10^{-15} @ 1550 nm	0.5 nA @ 5 V	1.0 pF @ 5 V
FGA10	InGaAs	700-1800	0.81 mm^2 (Ø1 mm)	TO-5/ PIN	10 ns (10 ns) @ 5 V	2.5×10^{-14} @ 900 nm	100 nA @ 5 V (max)	80 pF @ 0 V
FGA20	InGaAs	1200-2600	0.79 mm^2 (Ø1 mm)	TO-18/ PIN	23 ns (23 ns) @ 1 V	2.0×10^{-12}	75 µA @ 1 V (max)	200 pF @ 1 V
FGA21	InGaAs	800-1800	3.14 mm^2 (Ø2 mm)	TO-5/ PIN	66 ns (66 ns) @ 0 V	3.0×10^{-14} @ 2300 nm	200 nA @ 1 V	500 pF @ 0 V
DSD2	Si and InGaAs	Si: 400-1100 InGaAs: 1000-1700	Si: Ø2.54 mm InGaAs: Ø1.5 mm	TO-5/ PIN	4 µs typical (both layers)	Si: 1.9×10^{-14} InGaAs: 2.1×10^{-13}	-	Si: 450 pF InGaAs:300 pF
FDS02	Si	400-1100	0.25 mm	TO-46 FC/PC Connector	47 ps (246 ps) @ -5 V	9.3×10^{-15}	35 pA (500 pA max.) @ 5 V	0.94 pF @ 5 V
FDS010	Si	200-1100	0.81 mm^2 (Ø1 mm)	TO-5/ PIN	<1 ns (<1 ns) @ 20 V	5.0×10^{-14} @ 900 nm	2.5 nA	10 pF @ 0 V
			13 mm^2	[illegible]	[illegible]	[illegible]		[illegible]

Solar cells: converting light to electricity





Solar cell technologies

Single crystal silicon cells (c-Si)

Thin film solar cells

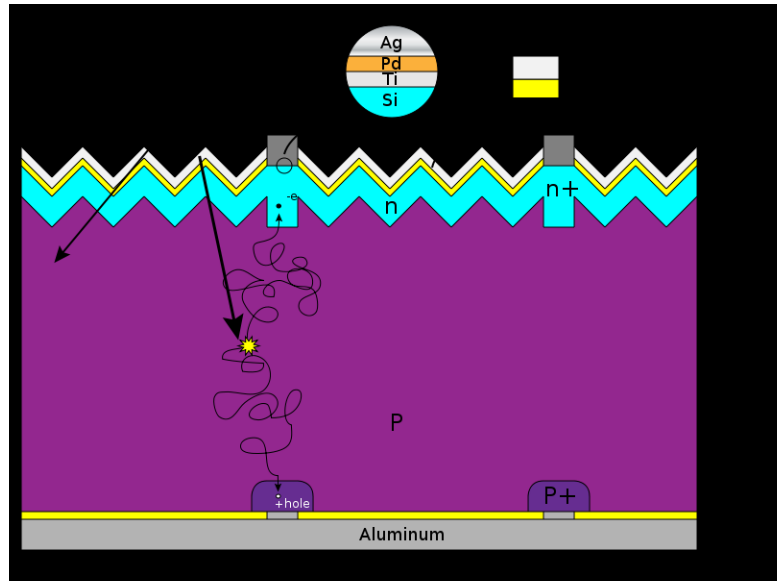
- Amorphous silicon (a-Si)
- Polycrystalline silicon (poly-Si)
- Cadmium telluride (CdTe)
- Copper indium gallium diselenide (CIGS) alloy

New emerging technologies

- Polymer solar cells
- Dye sensitized solar cell (DSSC)
- Hybrid - inorganic crystals within a polymer matrix

Single crystal silicon cells

Accounting for more than 86% of the solar cell market



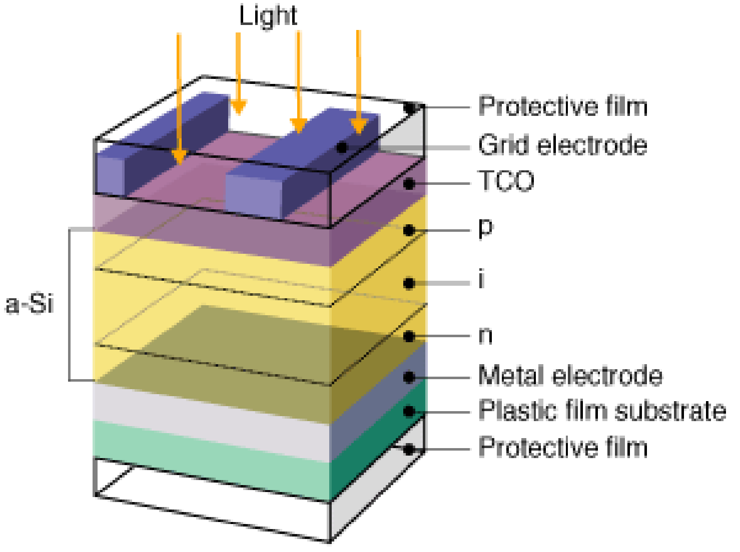
Requires expensive manufacturing technologies

Growing and sawing of ingots is a highly energy intensive process

Much of higher energy photons, at the blue and violet end of the spectrum, is wasted as heat

Thin film solar cells

Amorphous silicon cells deposited on stainless-steel ribbon, glass or polymer



Amorton Film Configuration

- Cadmium telluride (CdTe)
- Copper indium gallium diselenide (CIGS) alloy

Thin film solar cells

Advantages:

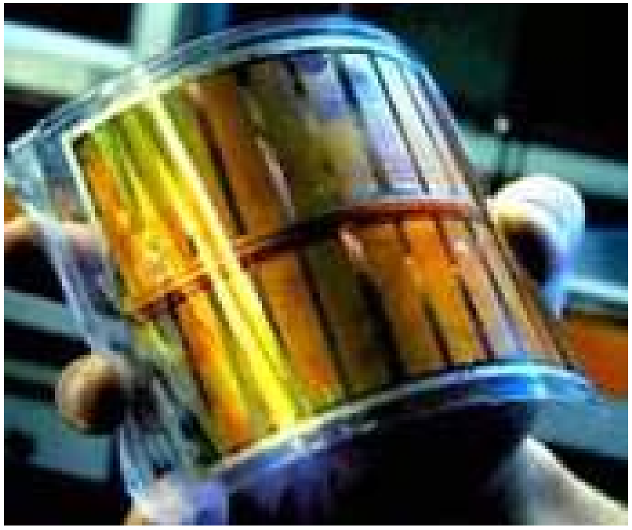
- Lower manufacturing costs
- Lower cost per watt can be achieved
- Reduced mass
- Less support is needed when placing panels on rooftops
- Allows fitting panels on light or flexible materials, even textiles

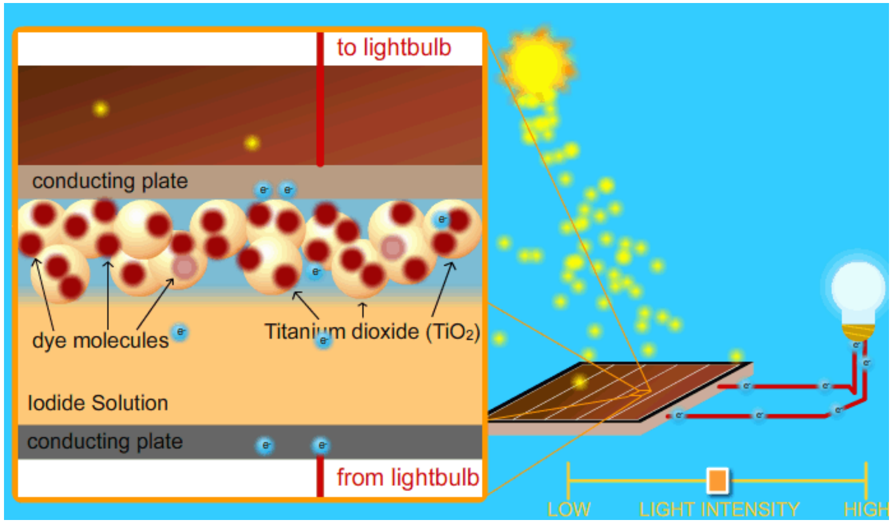
Disadvantages

- Typically, the efficiencies of thin-film solar cells are lower compared with silicon (wafer-based) solar cells
- Amorphous silicon is not stable

New emerging technologies

- Polymer solar cells
- Dye sensitized solar cell (DSSC)
- Hybrid - inorganic crystals within a polymer matrix





Dye sensitized solar cell (DSSC)

New emerging technologies

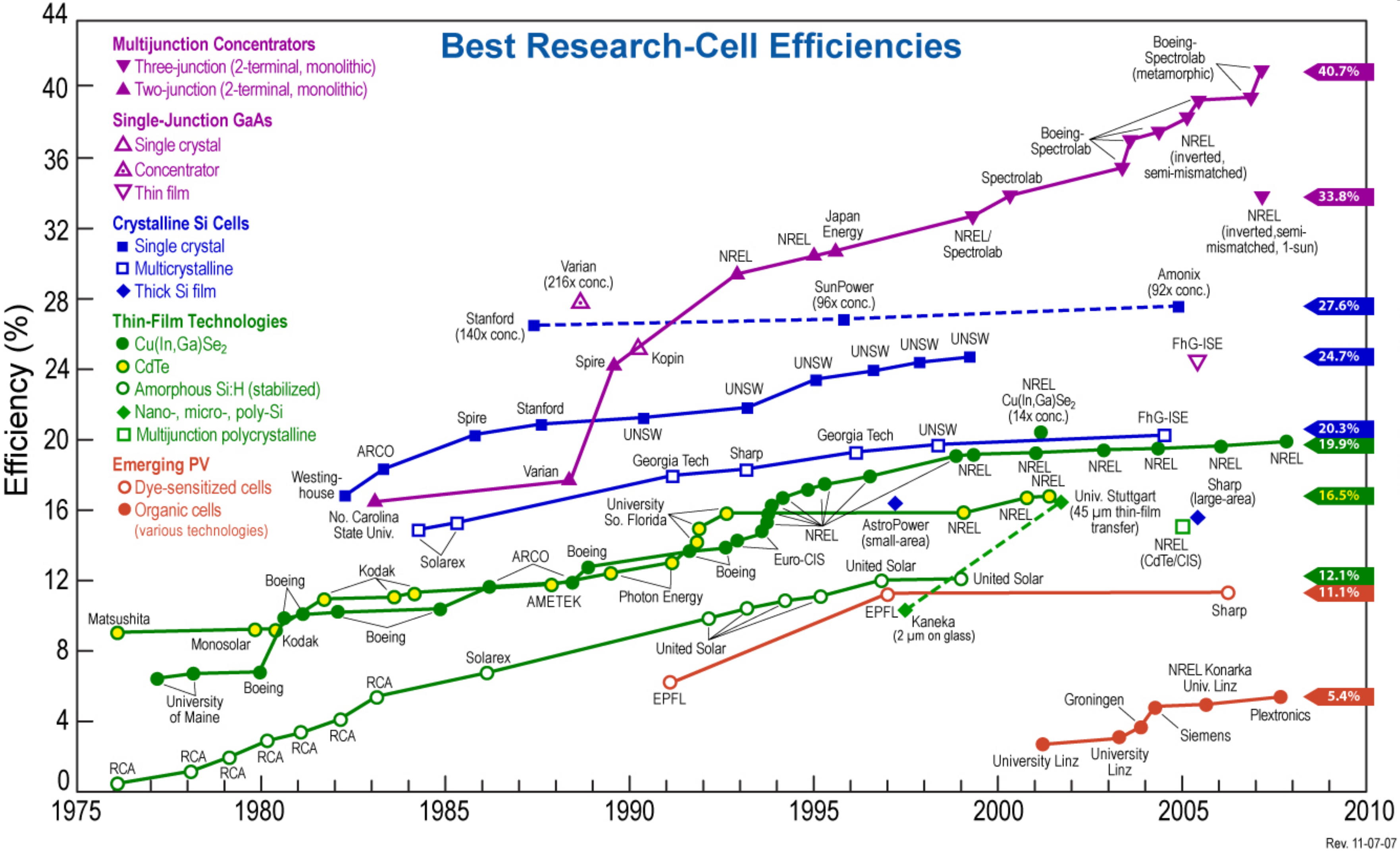
Advantages

- Low-energy, high-throughput processing technologies
- Polymer cells - solution processable, chemically synthesized
- Polymer cells - low materials cost

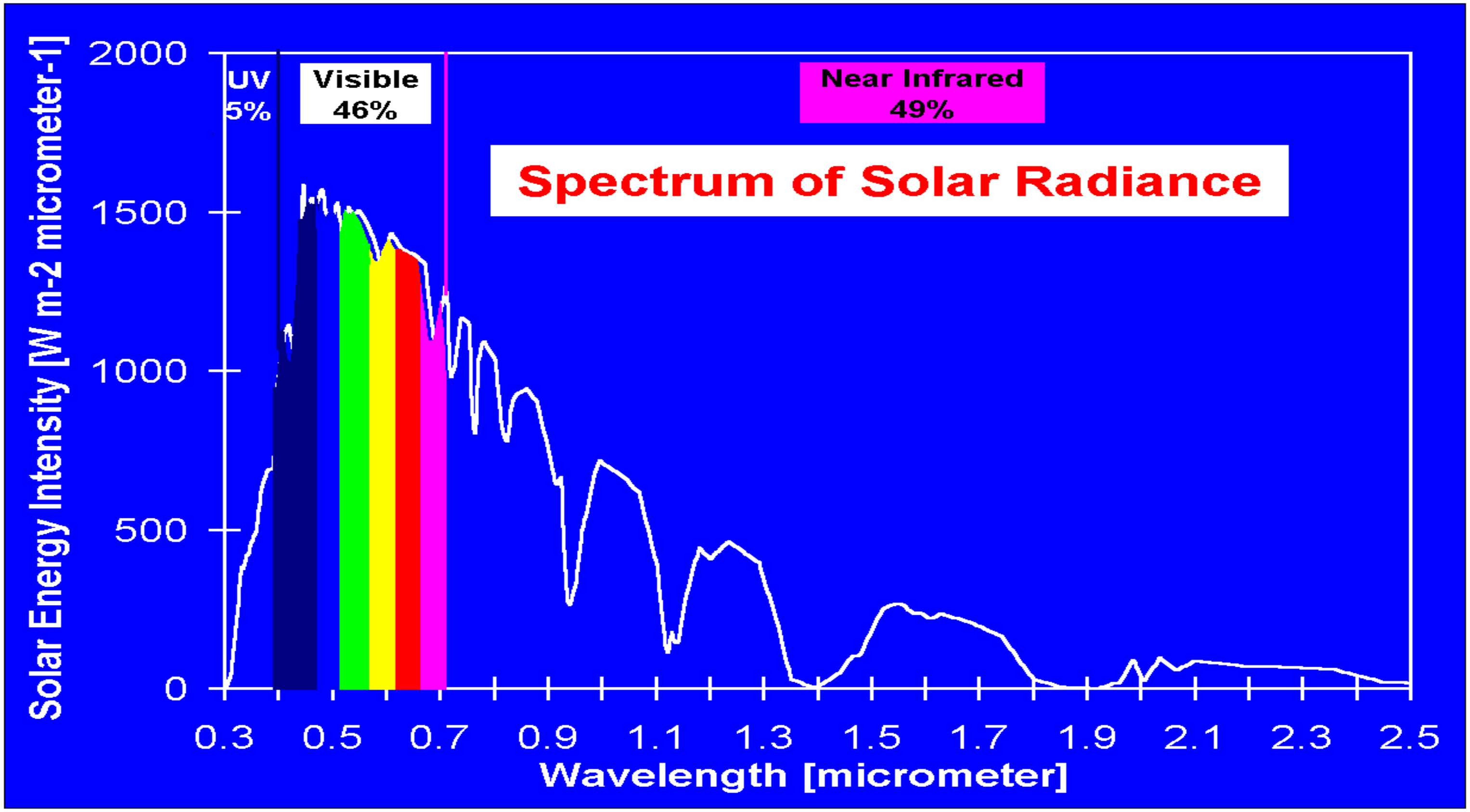
Disadvantages

- Efficiencies are lower compared with silicon (wafer-based) solar cells
- Polymer solar cells:
  - Degradation effects: efficiency is decreased over time
  - High band gap
- Dyed sensitized cells suffer from degradation of the electrodes from the electrolyte

Solar cell efficiency

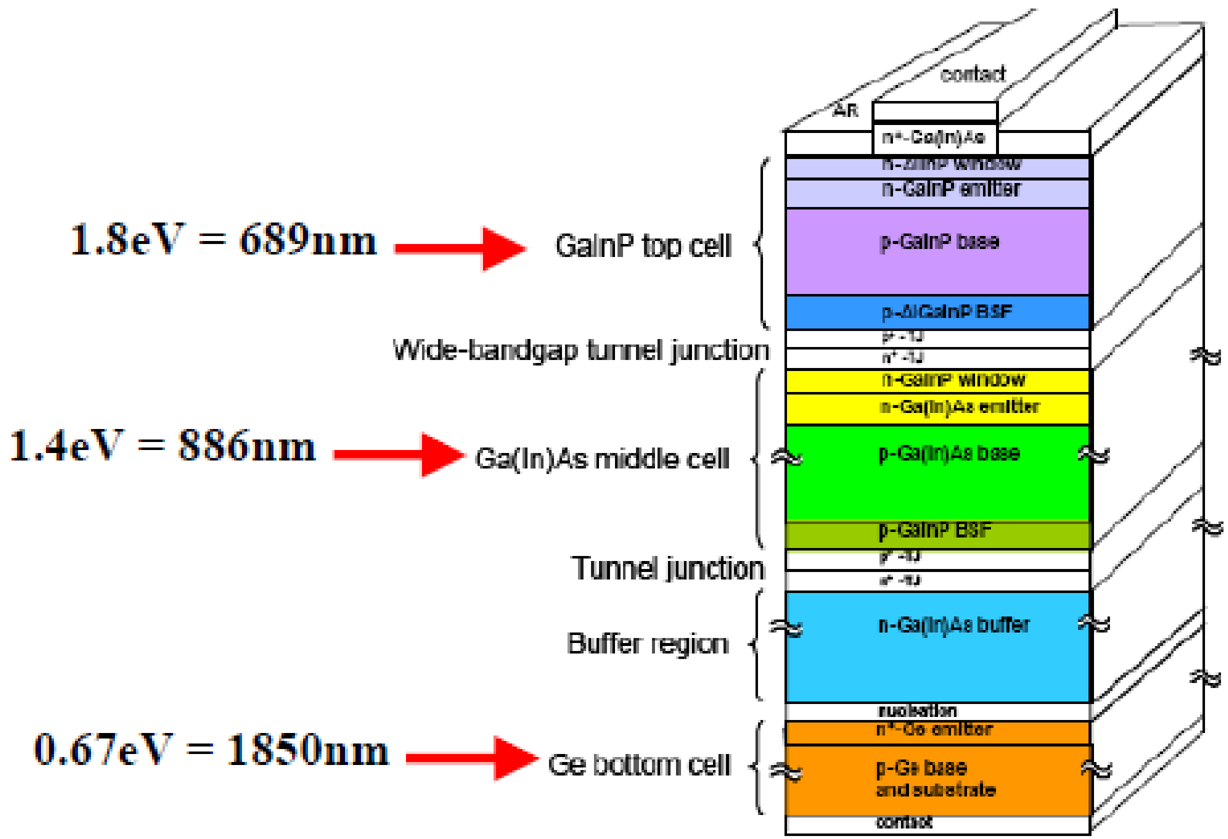


Solar power spectrum



- Power reaching earth 1.37 KW/m2

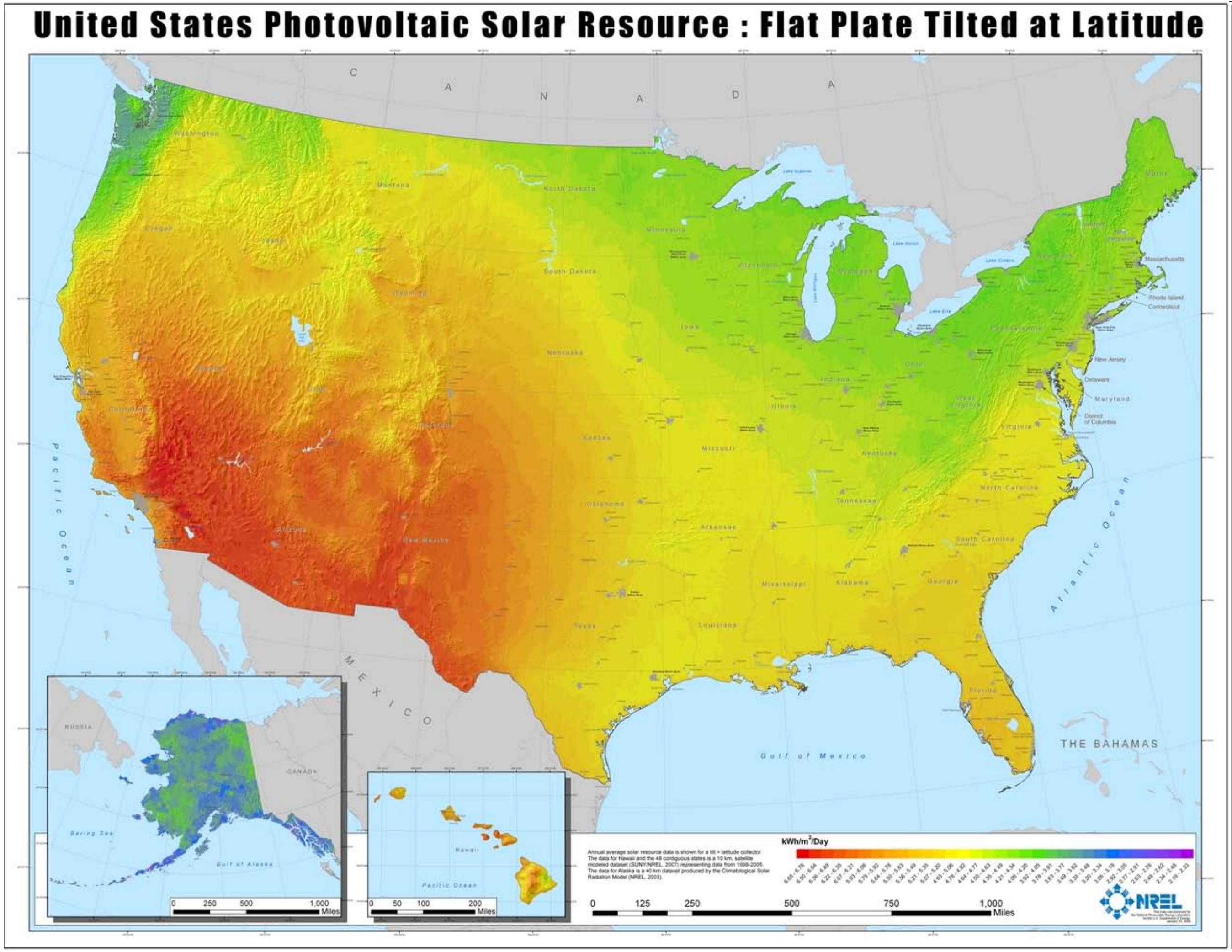
Multi-junction solar cells



Concentrated solar collectors

Provide the best efficiency (> 40%) in conjunction with multi-junction cells

Solar cells


United States Photovoltaic Solar Resource : Flat Plate Tilted at Latitude
kWh/m²/Day
THE BAHAMAS
Gulf of Mexico
MEXICO
CANADA
Pacific Ocean
Atlantic Ocean
NREL

Solar cells

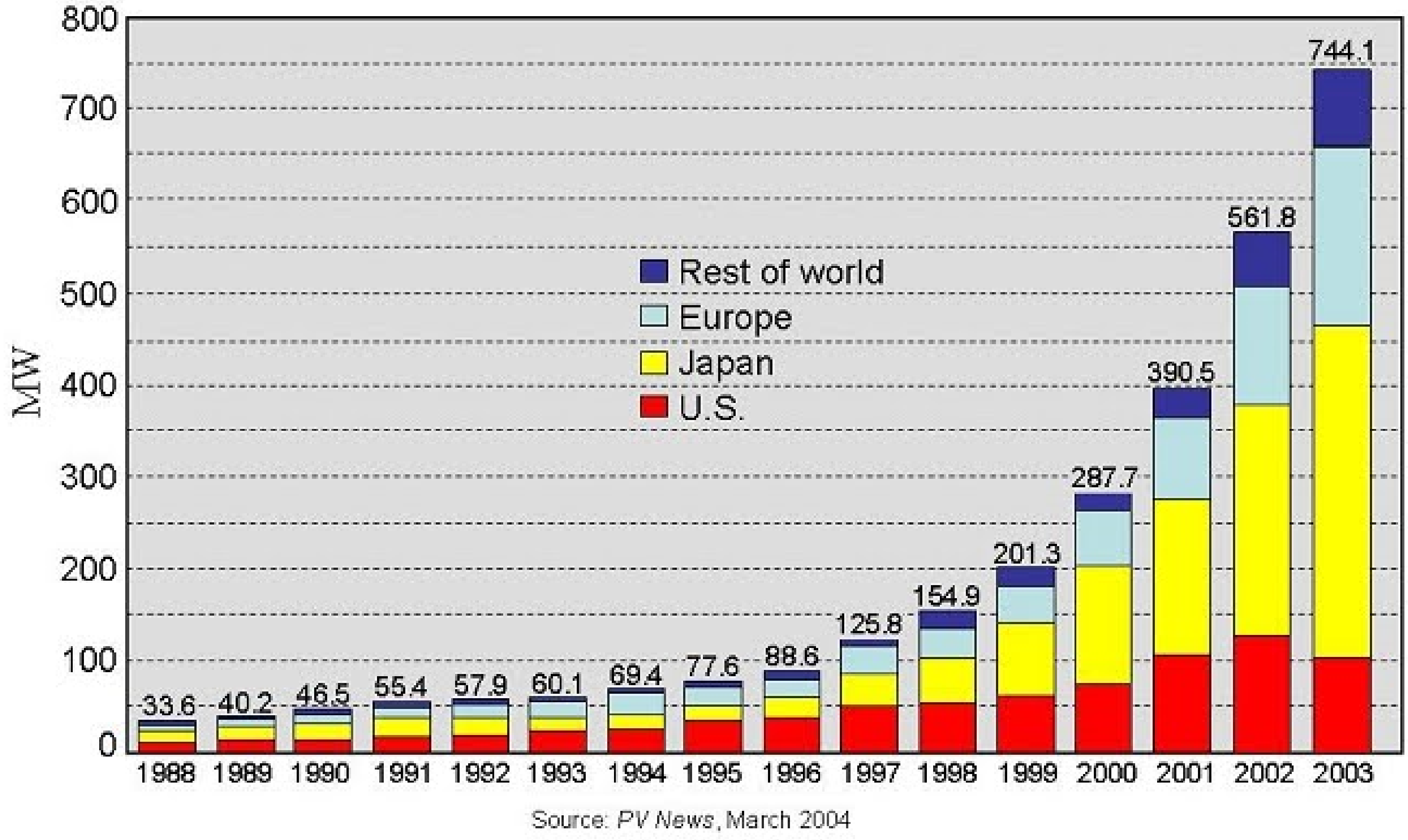


Figure 1 World PV cell/module production (in MW_p)

Solar cells

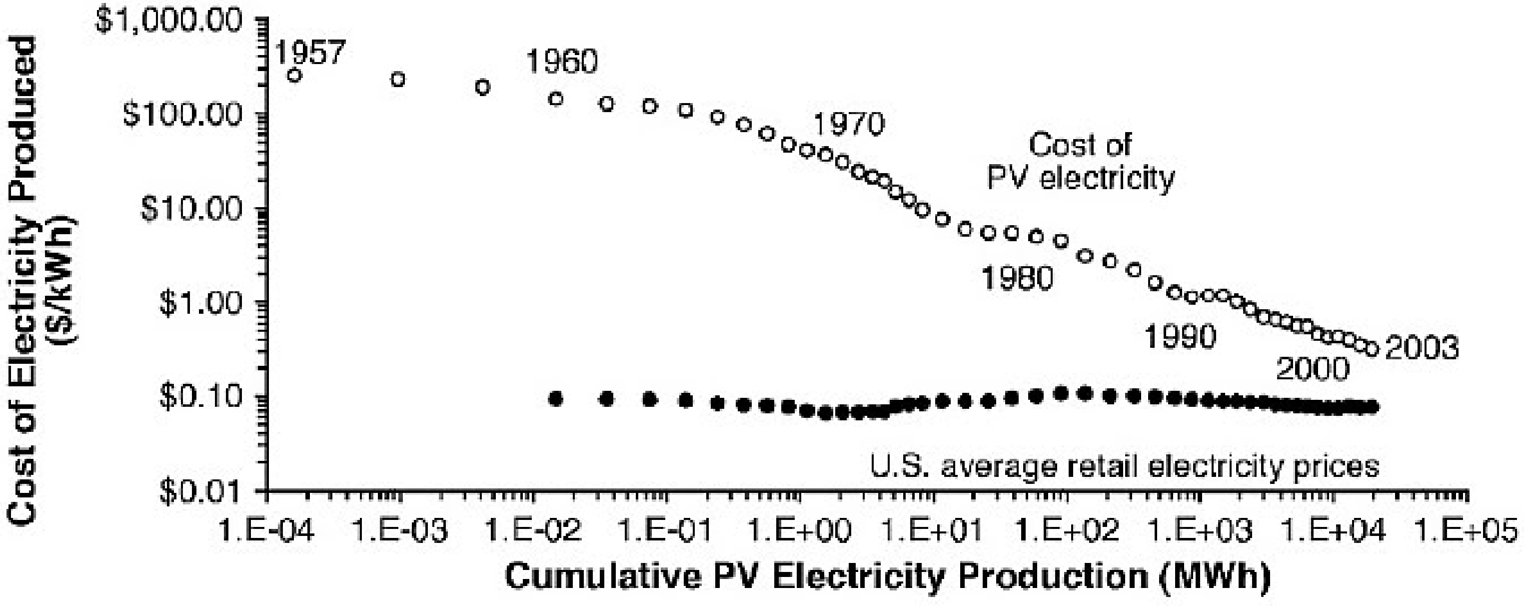
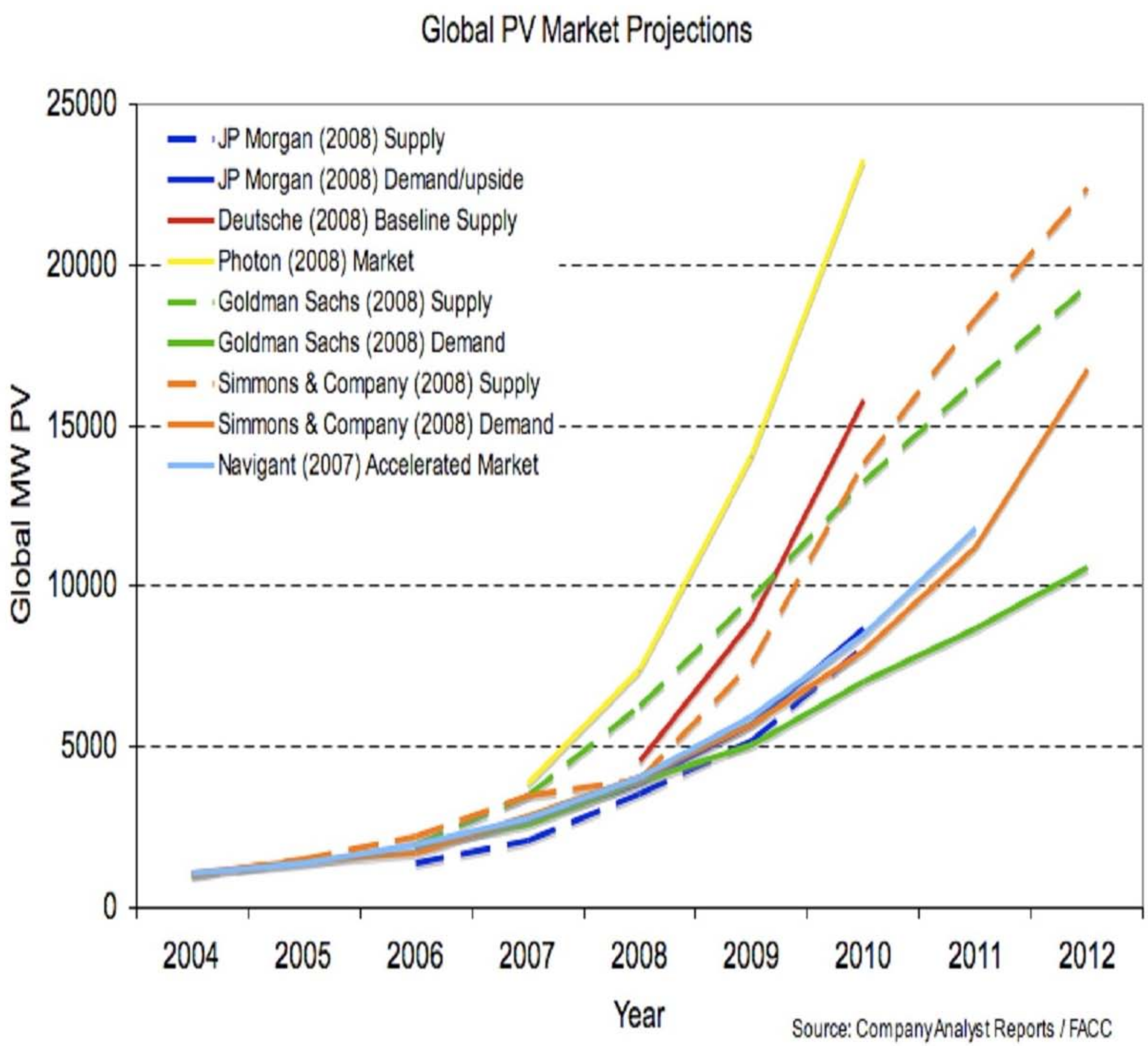


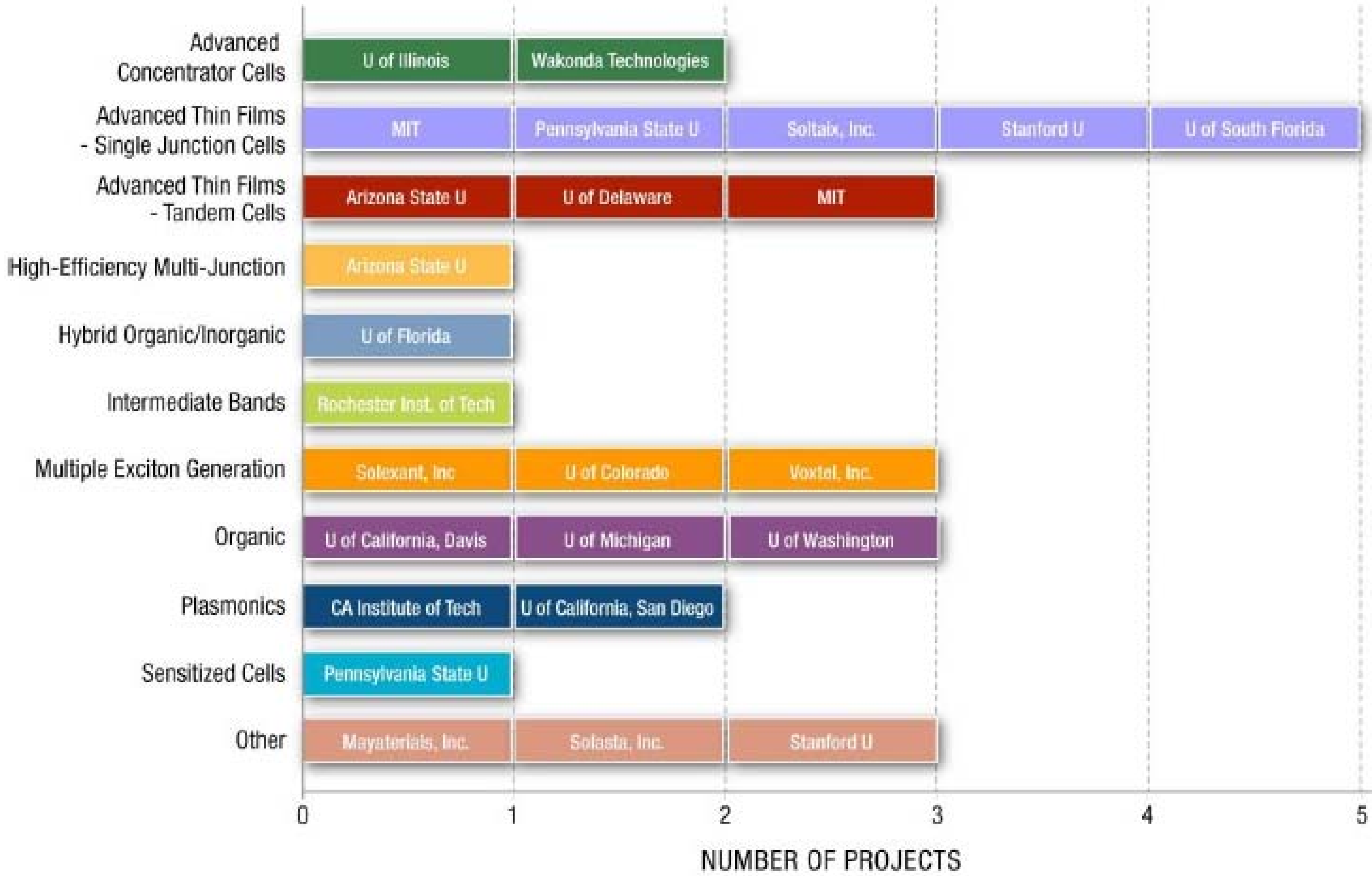
Figure 5. Aggregate cost of electricity in the US, versus cost of PV electricity [11].

Solar cells



Global PV Market Projections
JP Morgan (2008) Supply
JP Morgan (2008) Demand/upside
Deutsche (2008) Baseline Supply
Photon (2008) Market
Goldman Sachs (2008) Supply
Goldman Sachs (2008) Demand
Simmons & Company (2008) Supply
Simmons & Company (2008) Demand
Navigant (2007) Accelerated Market
Global MW PV
25000
20000
15000
10000
5000
0
2004
2005
2006
2007
2008
2009
2010
2011
2012
Year
Source: Company Analyst Reports / FACC

Solar energy research projects



Thank you!