SOLAR ENERGY APPLICATION SYSTEMS

Concentrator Photovoltaics

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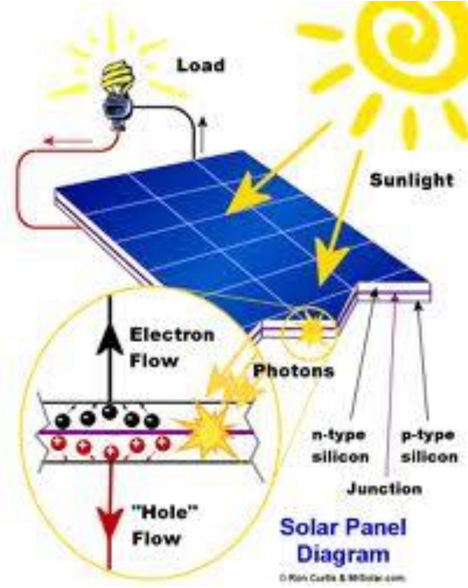
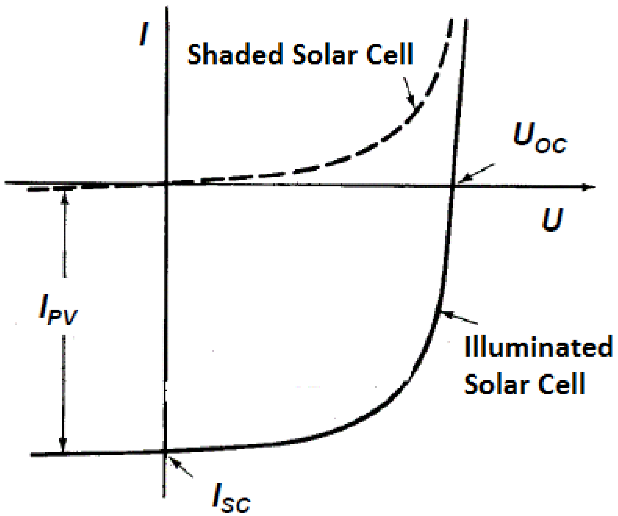
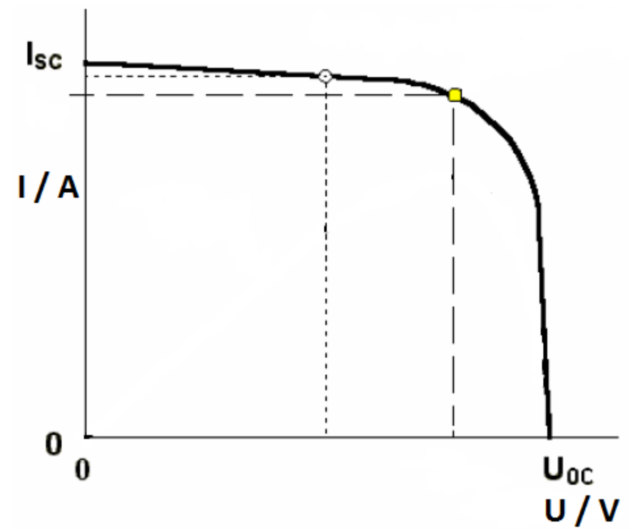
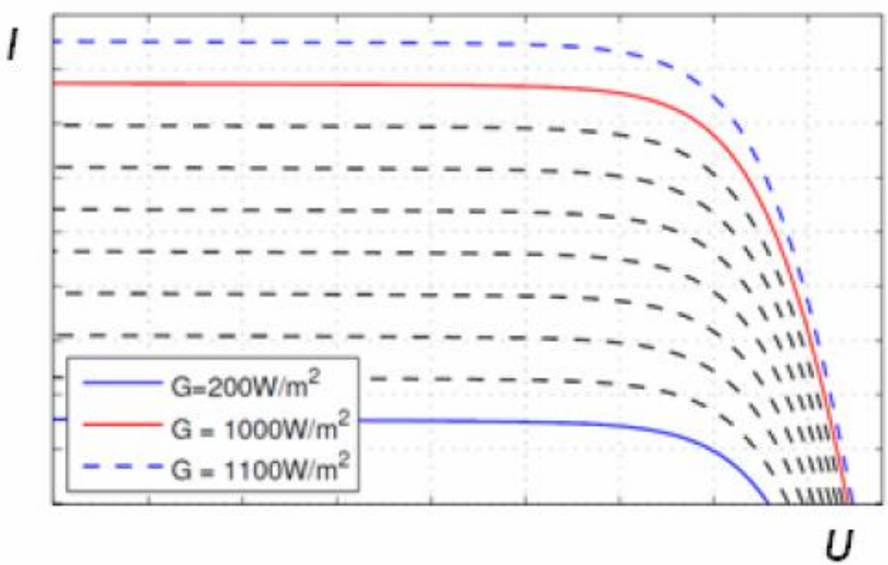
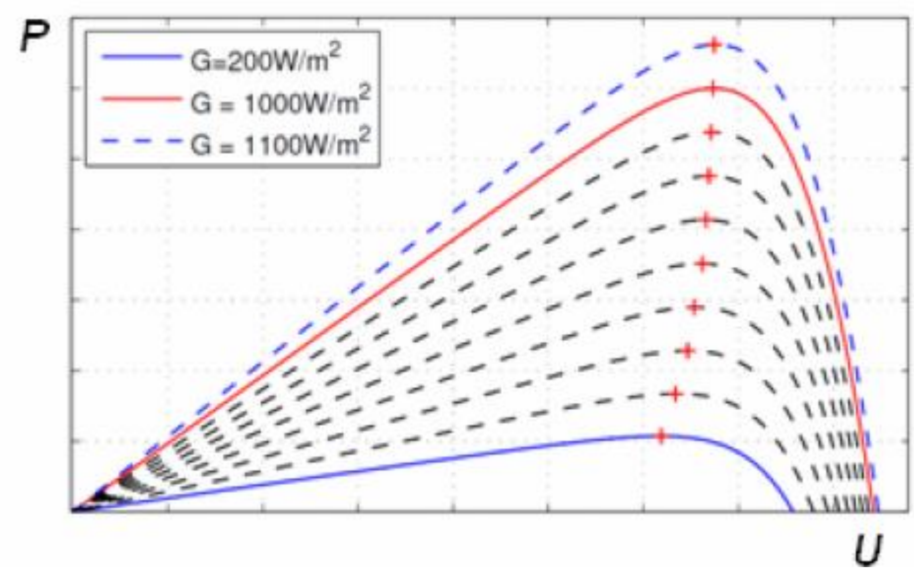
Solar Cell and Light



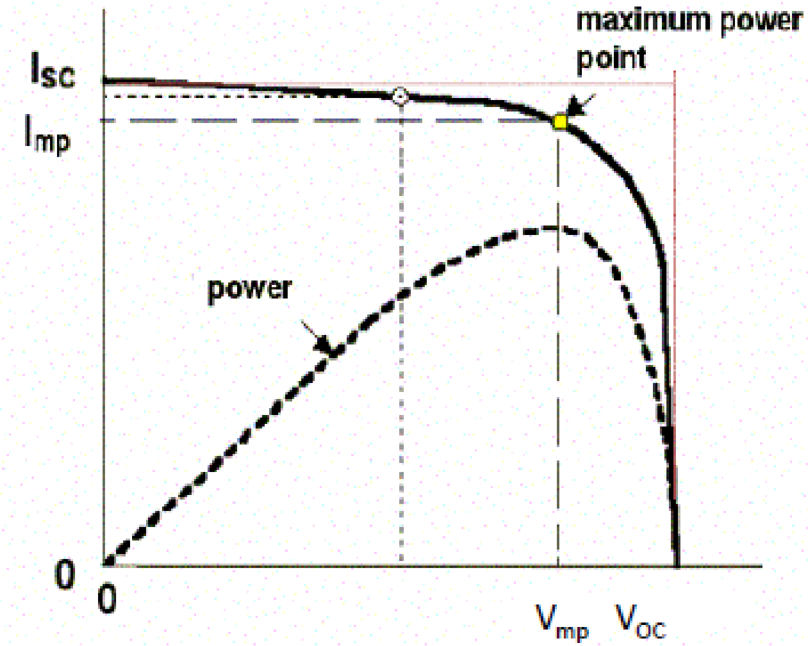


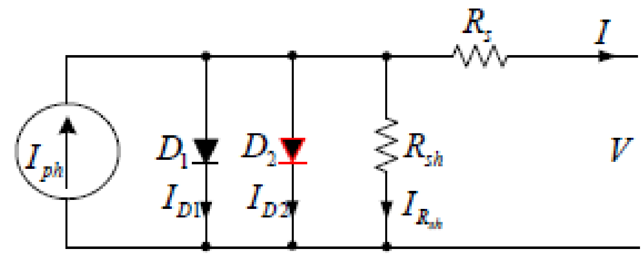






Standard Testing Conditions





$$I = I_{ph} - I_{01}\left(e^{\frac{V+IR_s}{V_{t1}}} - 1\right) - I_{02}\left(e^{\frac{V+IR_s}{V_{t2}}} - 1\right) - \frac{V+IR_s}{R_{sh}}$$

A_1, A_2 - diode ideality factors, I_{01}, I_{02} - dark saturation currents

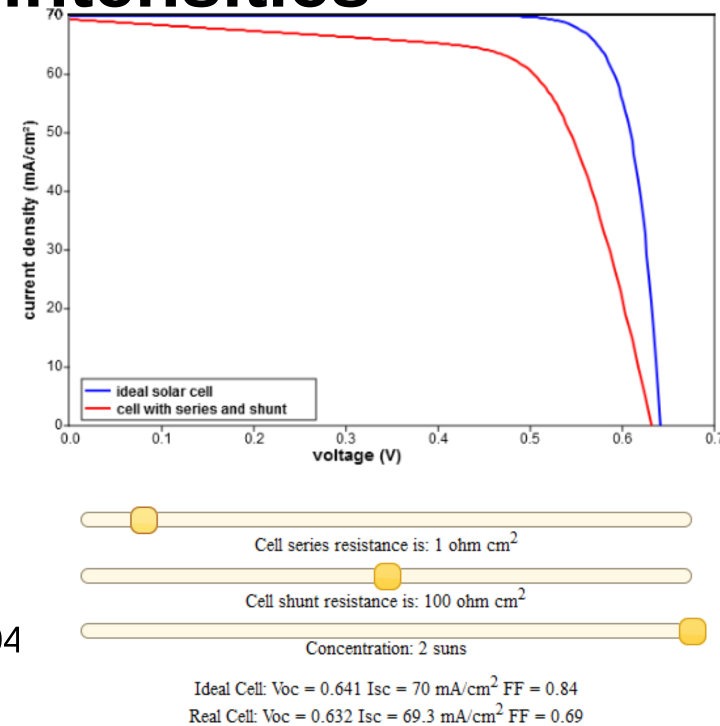
R_s - series resistance, R_{sh} - shunt resistance

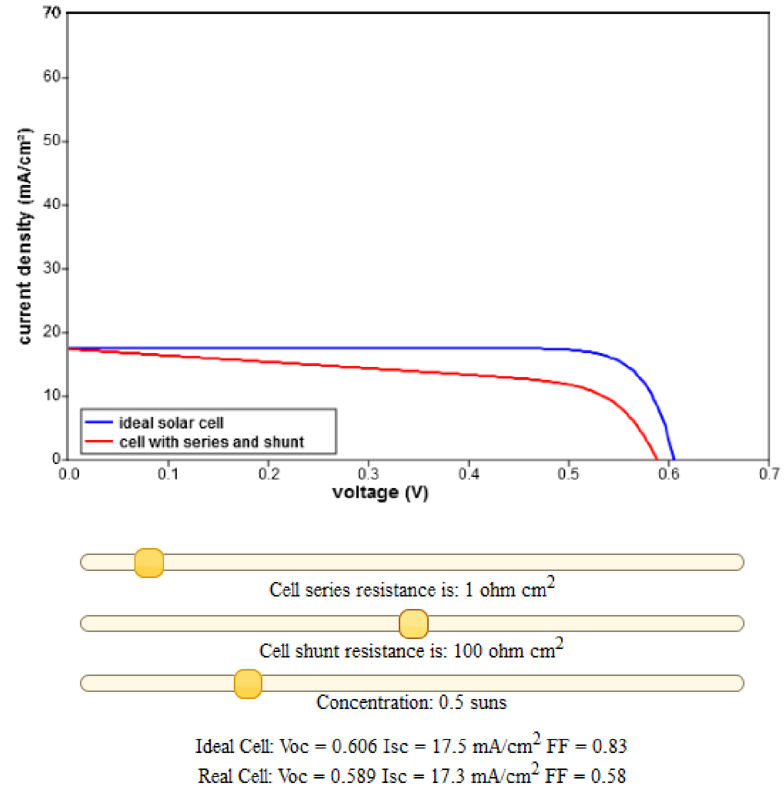
- Direct measurement of voltage and current (V_{OC} and I_{SC})
- Standard Testing Conditions: 25°C, **1000 W.m^{-2}**, AM = 1.5

1000 W.m^{-2} = 1 SUN

Effect of Light Intensity

- http://pveducation.org/pvcdrom/solar-cell-operation/effect-of-light-intensity
- $\mathbf{R_{SS}}$ greater effect on performance at **high light intesities**
- $\mathbf{R_{SH}}$ greater effect on performance at **low light intensities**

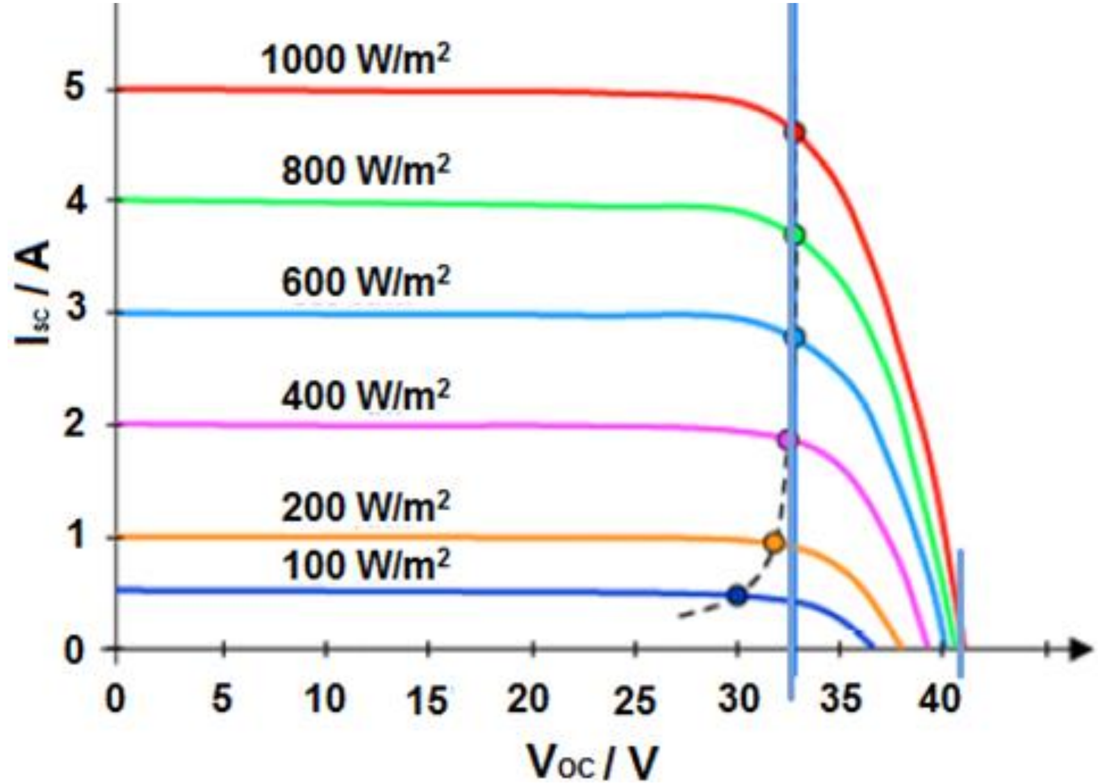




Effect of Light Intensity

- I_{SC} **increases linearly**
- V_{OC} **increases logarithmicaly**
- **η increases logarithmically**

$$\eta = \frac{U_{MPP} \cdot I_{MPP}}{P_{IN}}$$

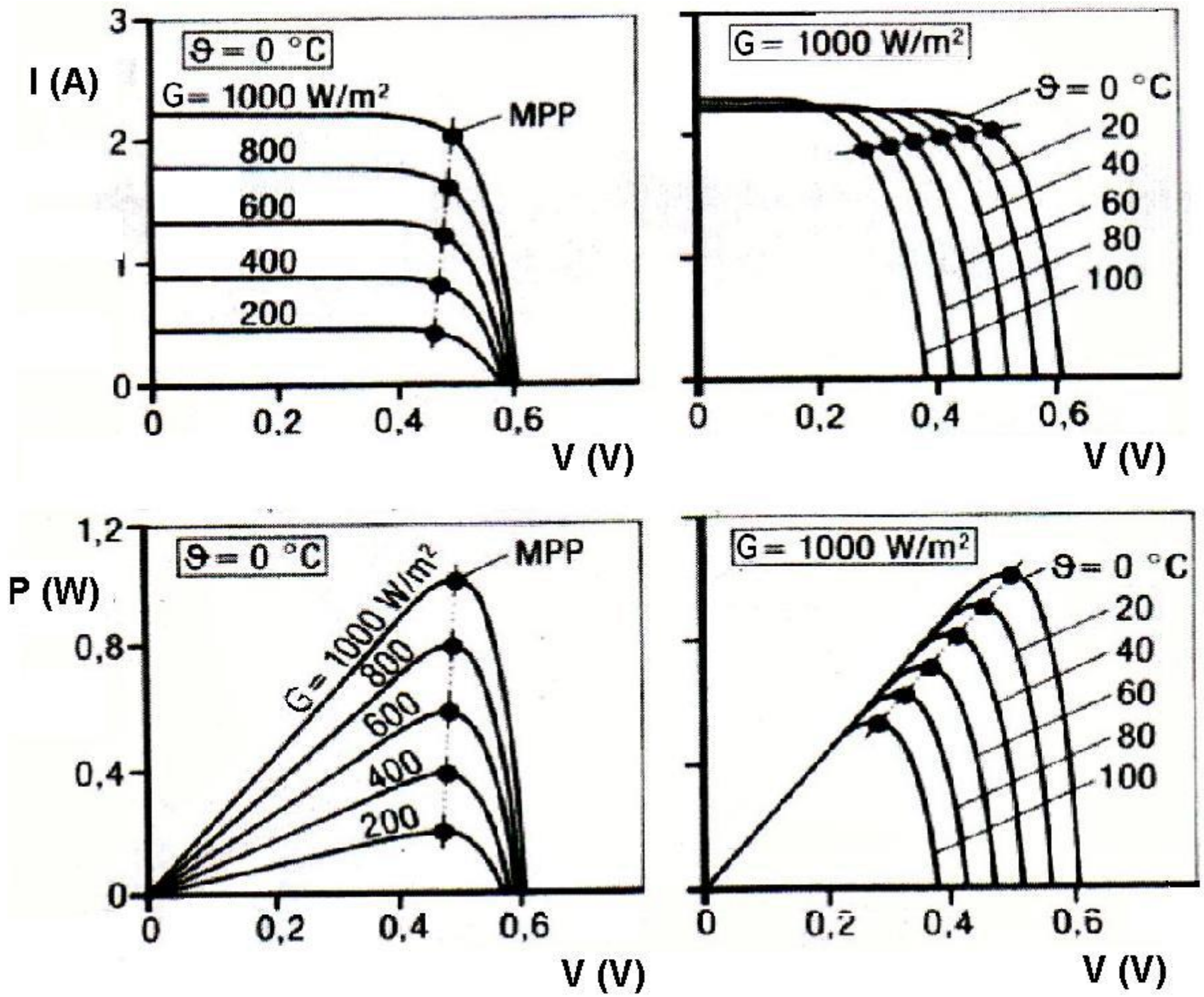


$$A_{ill} J_{PV} = I_{PV} >> I_{01} + I_{02} \longrightarrow V_{OC} \approx \frac{kT}{q} \ln \frac{I_{PV}}{I_{01}}$$

$$V'_{OC} = \frac{nkT}{q} \ln\left(\frac{X I_{SC}}{I_0}\right) = \frac{nkT}{q}\left[\ln\left(\frac{I_{SC}}{I_0}\right) + \ln X\right] = V_{OC} + \frac{nkT}{q} \ln X$$

Effect of Light Intensity

- **Benefit of higher efficiency can be compensated by losses in R_{SS} when I_{SC} and T increase**

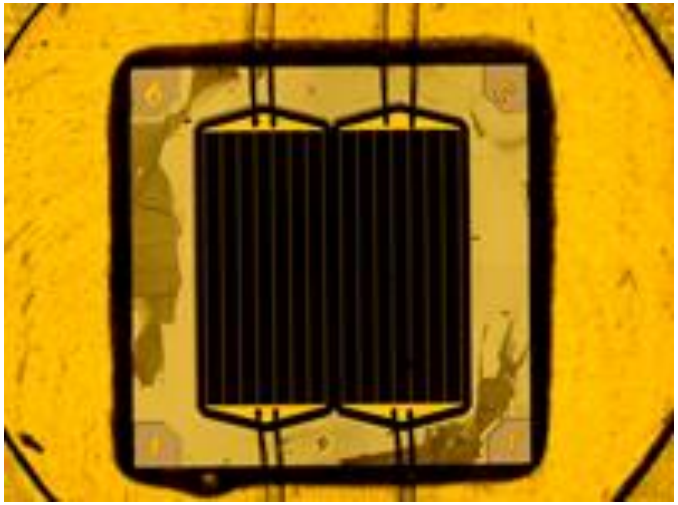


Why to Increase Light Intensity?

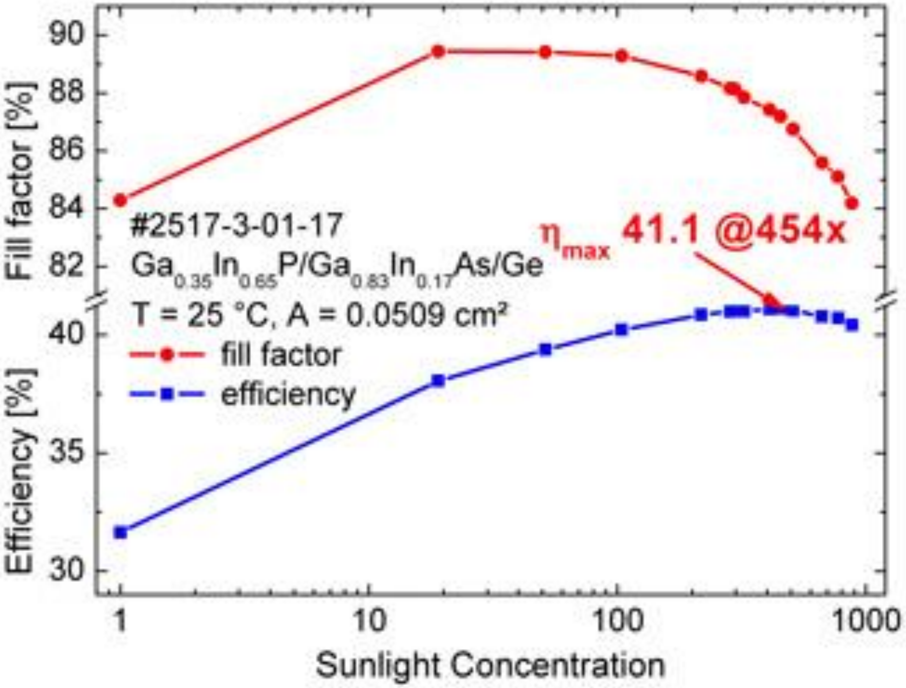
- Enhance of conversion efficiency
- Reduction of semiconductor material, costs

*Increase of a **solar cell efficiency** makes all the solar system more valuable*

Efficiency = f (Light Intensity)



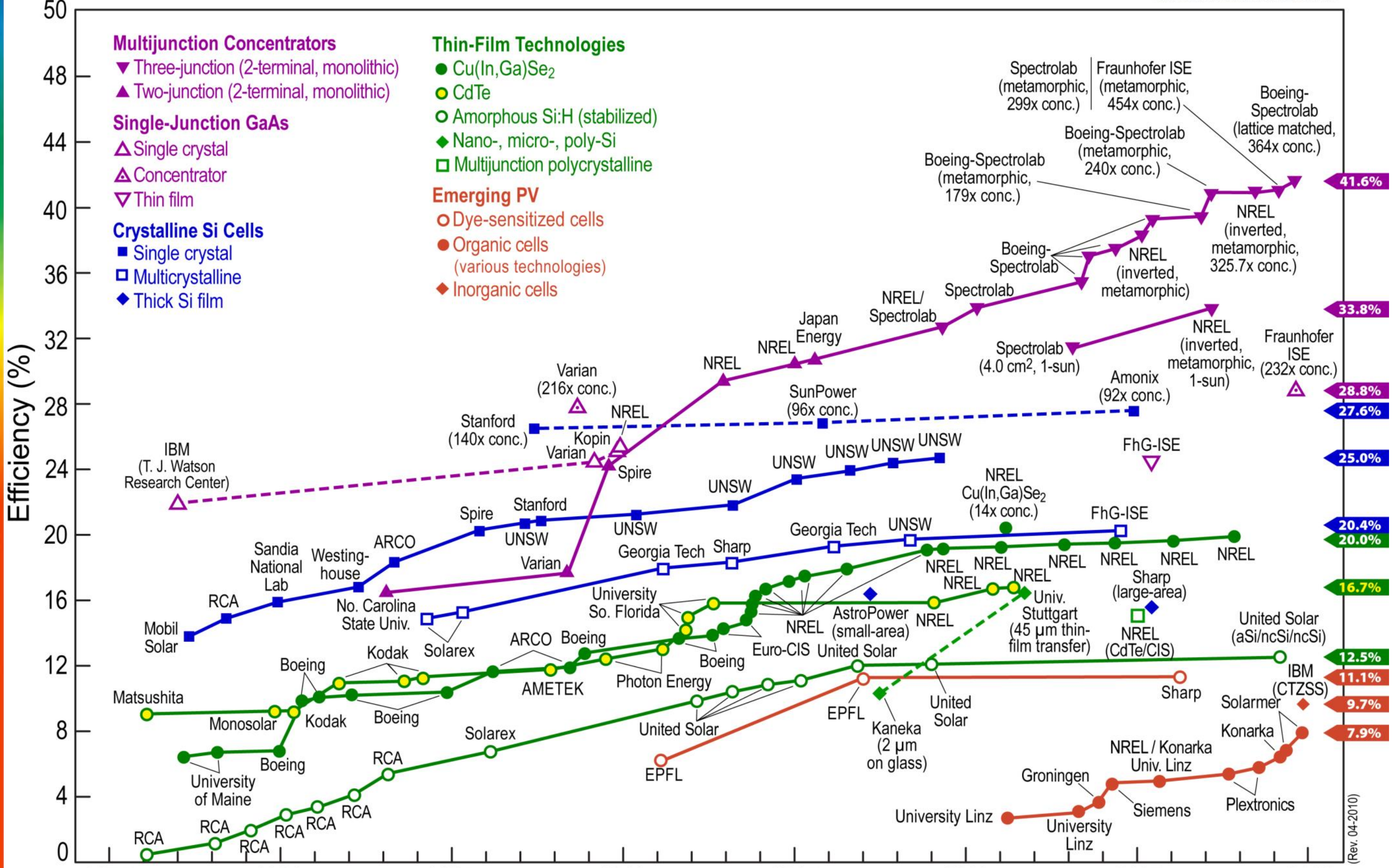
Picture (above): Record $Ga_{0.35}In_{0.65}P/Ga_{0.83}In_{0.17}As/Ge$ solar cell, with a cell area of 5.09mm².



15/04/2013

http://www.semiconductor-today.com/news_items/2009/JAN/FISE_150109.htm

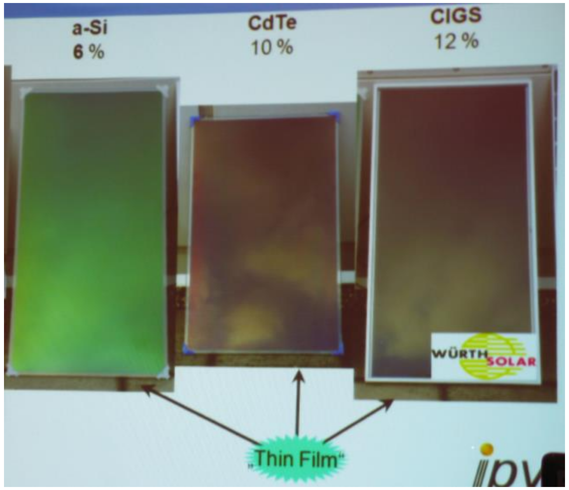
Best Research-Cell Efficiencies



Solar Cell Generations

- 1st generation
  - Wafer-based solar cells

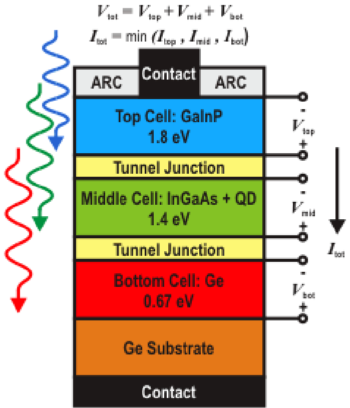
- 2nd generation
  - Thin film solar cells

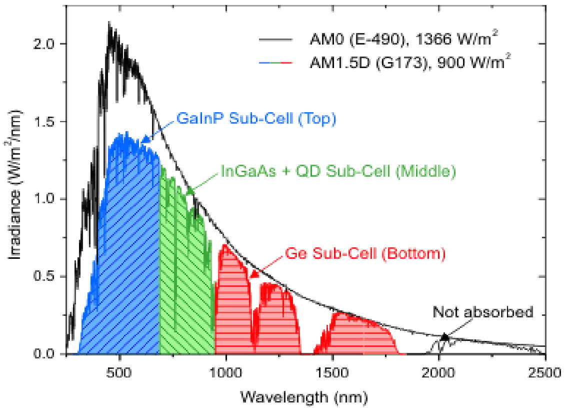


Prof. Weber, Conference HAWAII 2012

- 3rd generation
  - ??? maybe

  multi-junction solar cells





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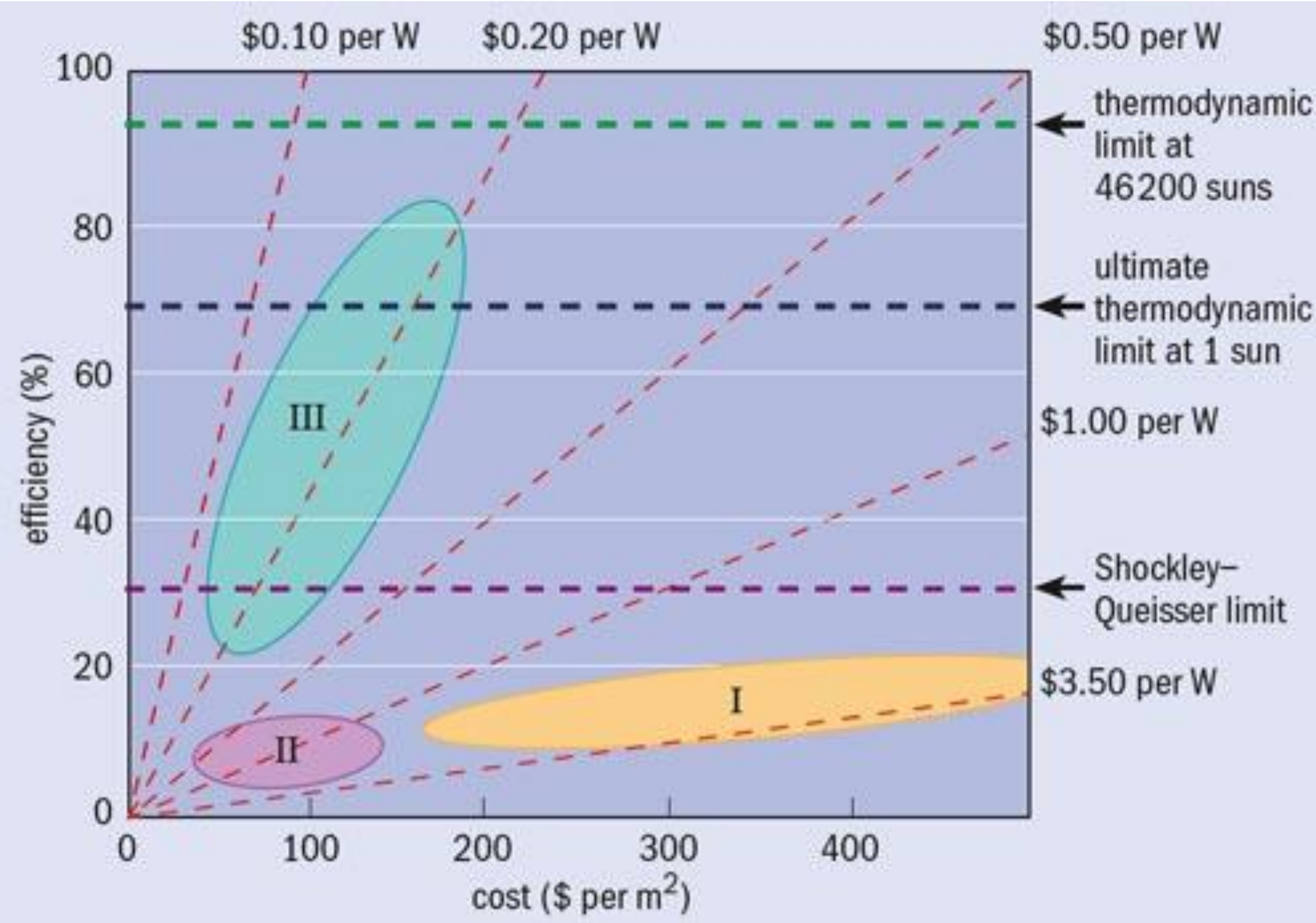
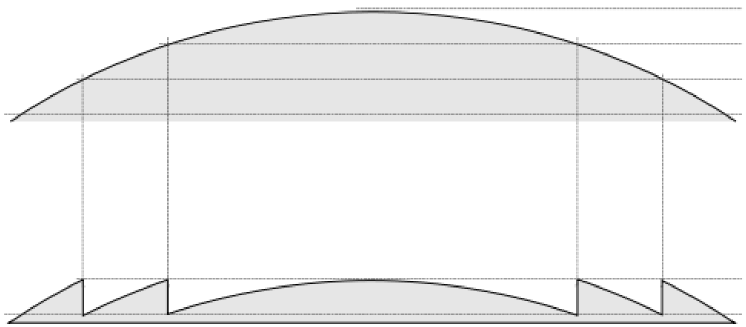
Costs versus Efficiency

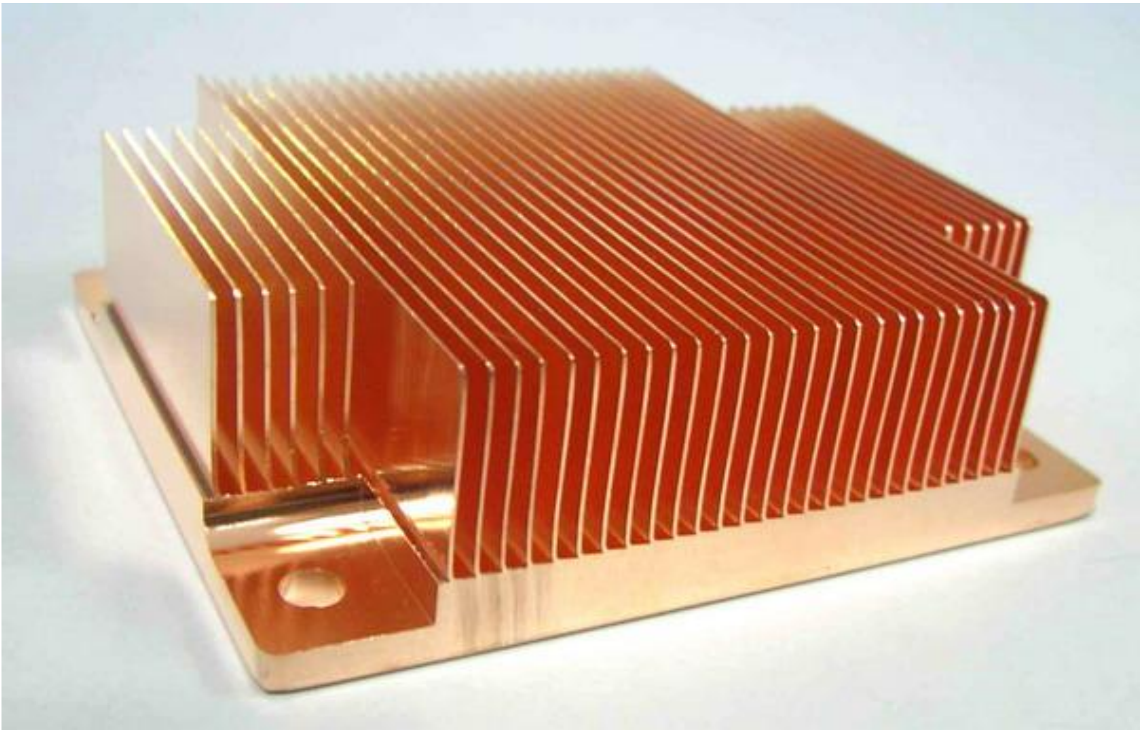


Components for Concentrator PV

- **Fresnel lens** to concentrate light

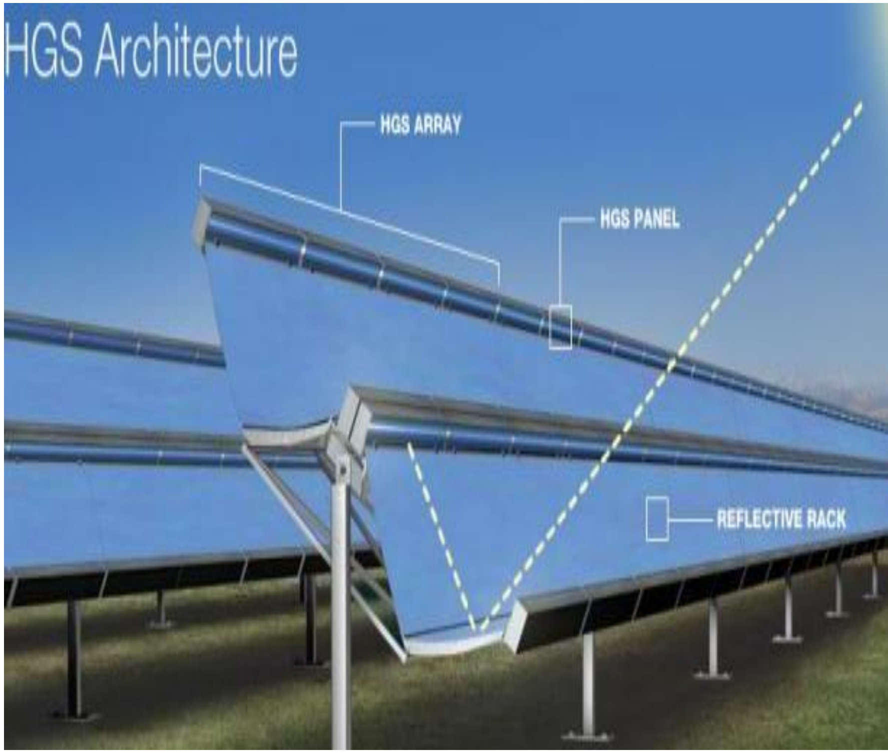


- **Heat sink** to cool a solar cell



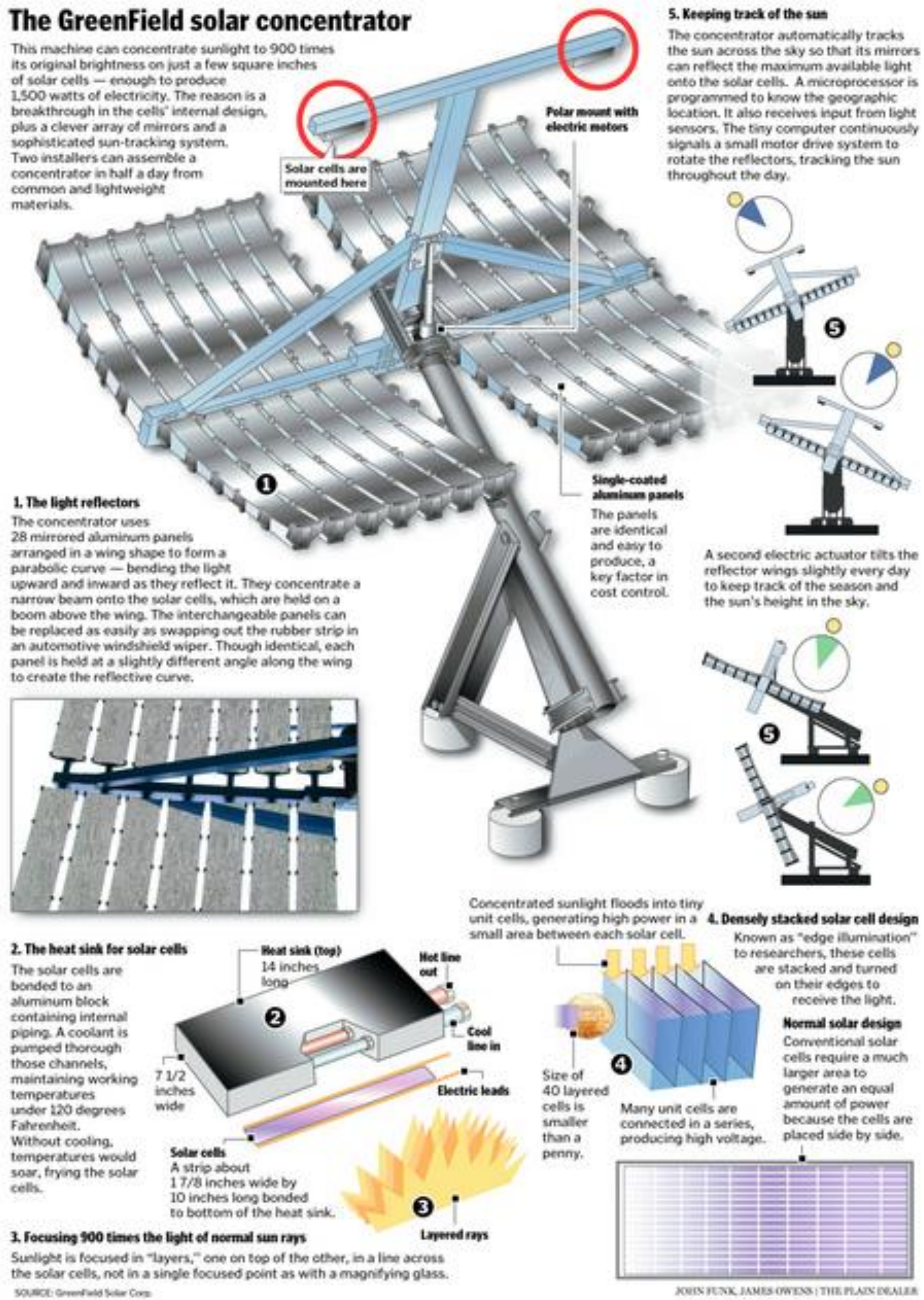
Low Concentration Systems

- 1-axis tracking system
  - Advantages:
    - Higher efficiency
    - Less semiconductor material
    - Rather use of conventional material
  - Disadvantages:
    - Higher installation costs (balance the system)



http://news.cnet.com/8301-11128_3-10232586-54.html

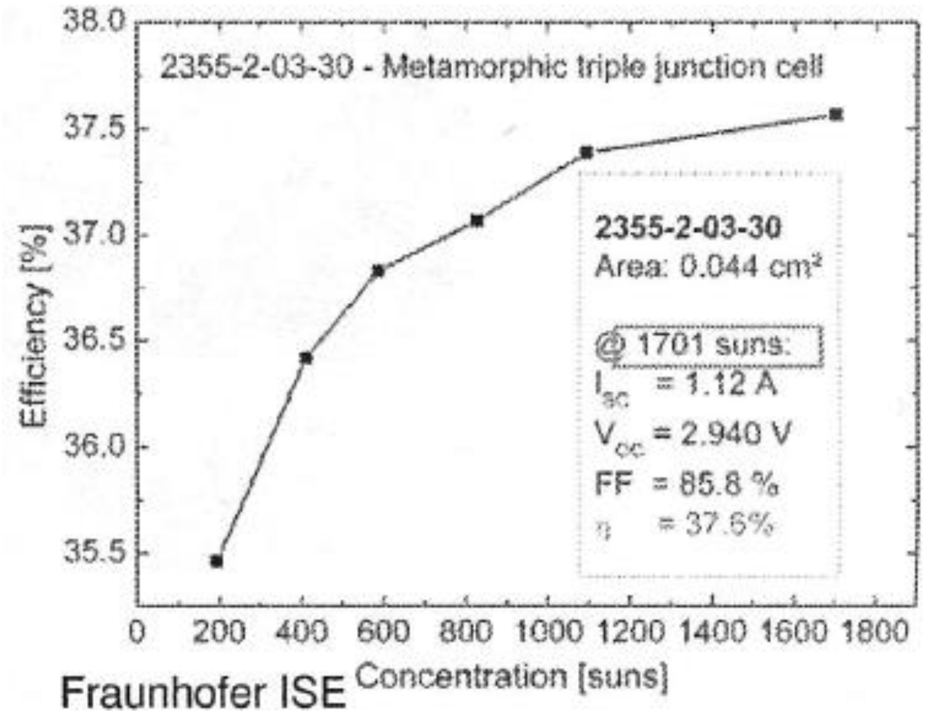
Skyline Solar concentrates light onto strips of monocrystalline silicon cells



http://blog.cleveland.com/business/2008/11/greenfield_solargreenfield_sol.html

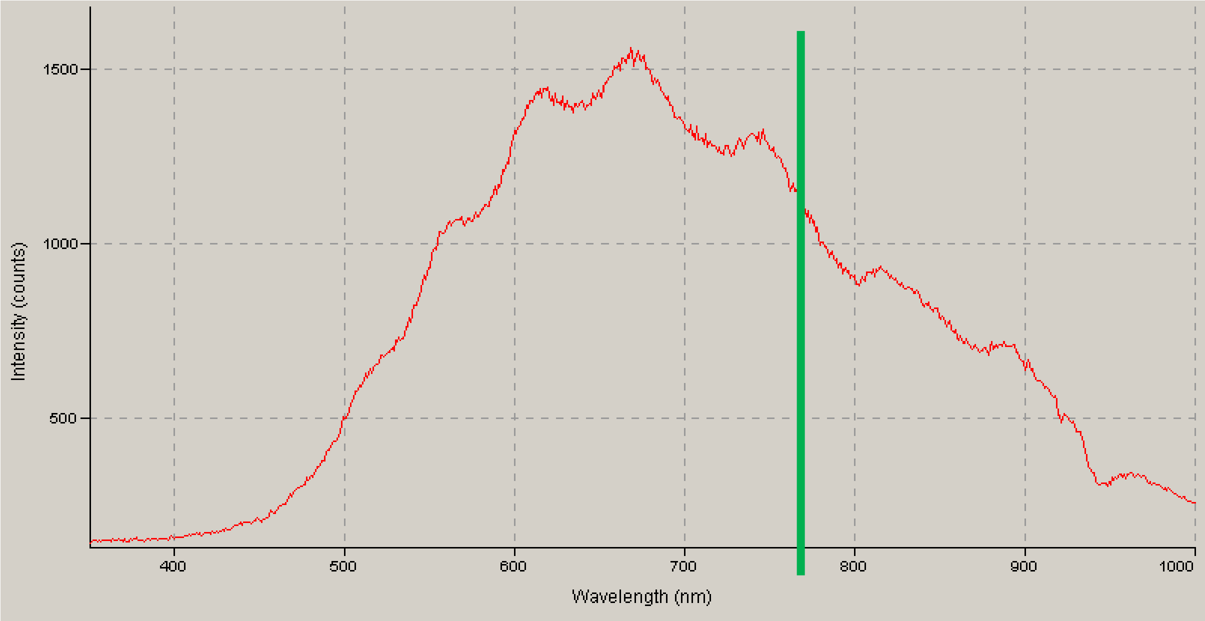
Concentrators

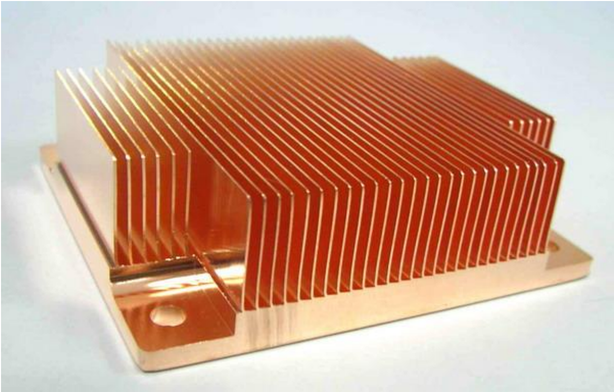
- Issues
  - Cell efficiency
  - Module efficiency
  - Balance of system
  - Tracking
  - Cooling

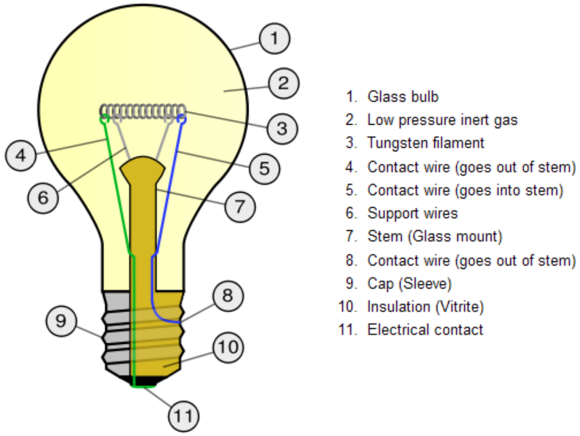


Why Cooling of Concentrator Cells?

- Light intensity at 1000 SUNS = 1MW/m^2.
- Cell size 10 mm^2 → power of incident light 10 W
- Solar cell efficiency η = 40 % → 4 W into electricity and **6 W into heat** → active cooling needed







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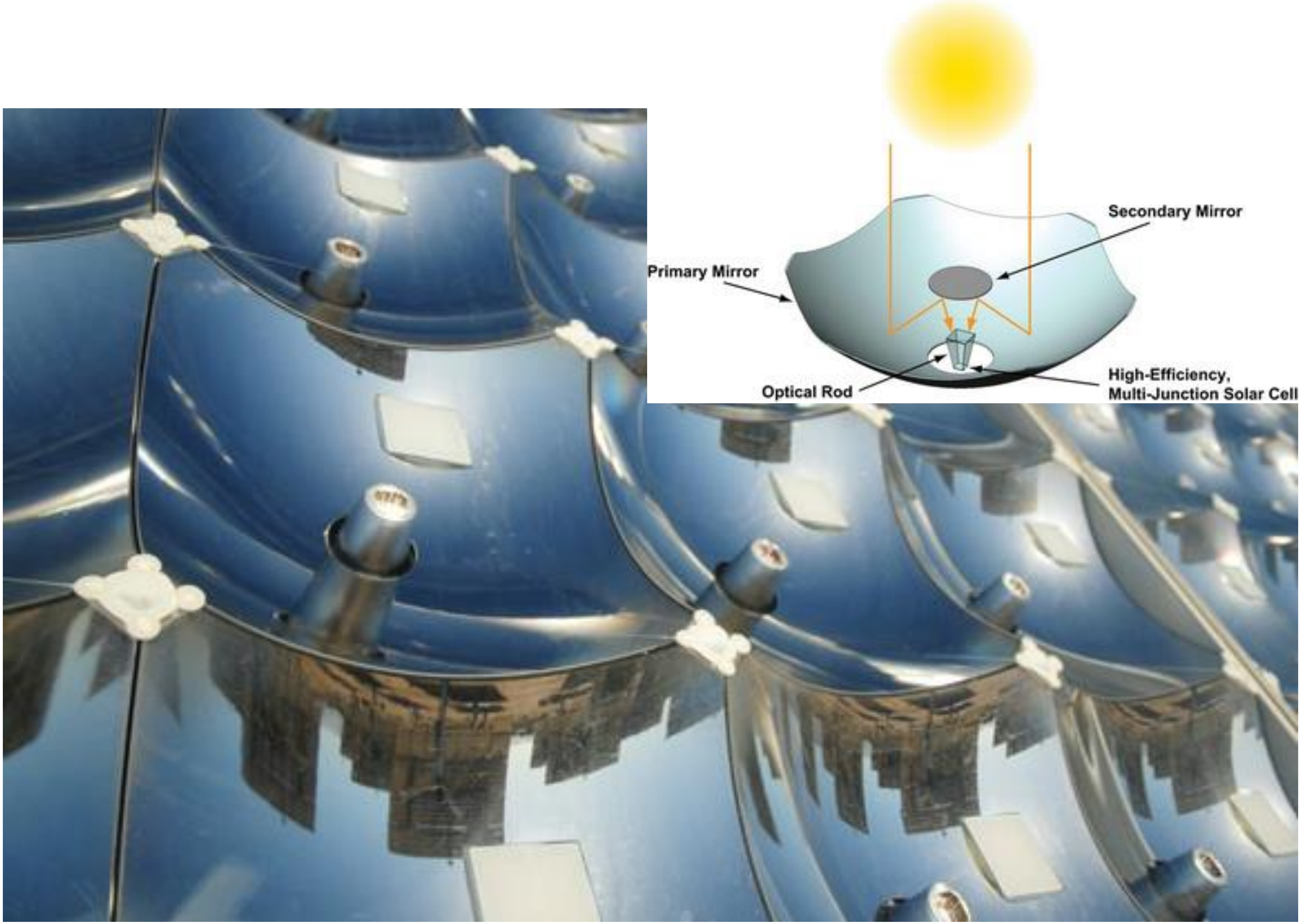
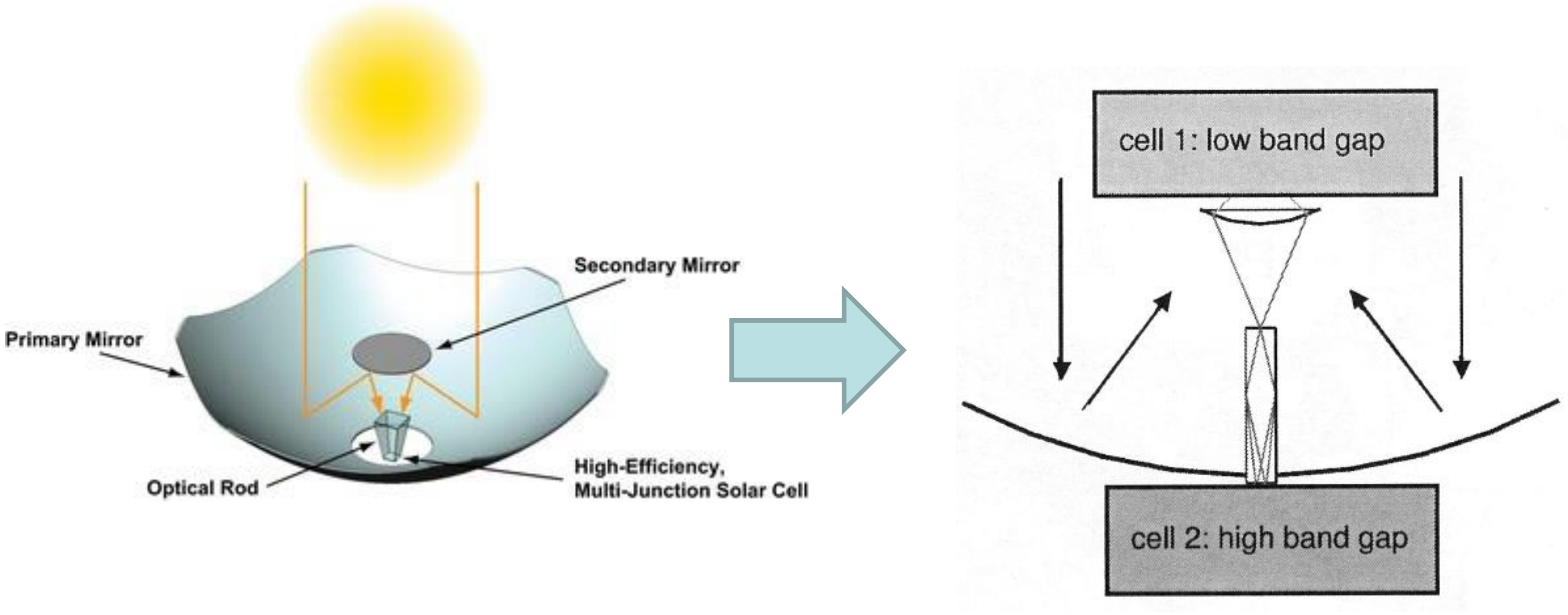
30% of power transfered into heat
100 W → 33 W is heat

SolFocus


Secondary Mirror
Primary Mirror
Optical Rod
High-Efficiency,
Multi-Junction Solar Cell

Spectrum Splitting

- Based on “cassegrainian” photovoltaic module
- Low energy solar cell and high energy solar cell



Heliostat Solar Concentrator

High Concentrated Photovoltaic (HCPV) / Combined Heat & Power (CHP) solar energy

How it works

Z20 features two 11m² collectors, mounted on a dual axis tracker that concentrates incoming solar power onto a receiver. The receiver consists of a multi junction PV coupled to heat exchanger that converts concentrated solar flux into electrical power (A) and thermal power (B).

(A) DC electrical power from the PV cells is converted to AC power and fed to the grid.

(B) Thermal energy is pumped through a closed loop system to the various users and applications such as:

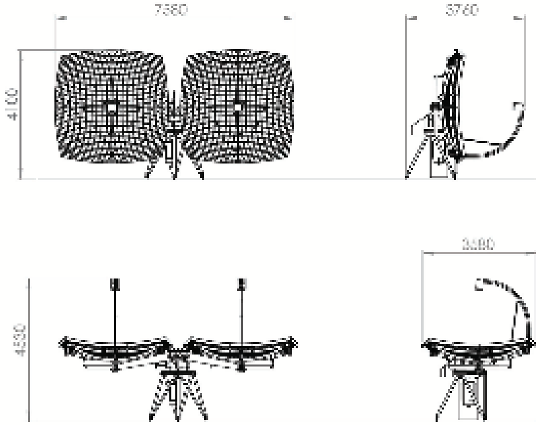
- Municipalities and district heating
- Hotels, Hospitals and resorts
- Industrial process heat: ideal for textile, food and pharmaceutical industry
- Thermal energy cooling can be converted into cooling or desalination and brackish water purification

Benefits

- Combined Heat and Power (CHP) generation
- Lowest cost per watt
- Industry highest combined efficiency of >72%
- Shortest possible return on investment
- Most suitable for hot climates
- Modular installations
- System design for easy upgrade - Multi Junction PV is the most progressing solar technology
- Best space utilization of land
- Proven field performance

Featuring

- 2 – axis high precision tracking mechanism with zero backlash, using performance feedback-driven, closed loop that continually positions the mirrors for maximum effectiveness
- State-of-the-art high efficiency Multi-Junction PV cells
- Engineered high efficiency multi-channel heat exchanger
- Designed for 20 year service, constructed from highly durable materials
- Environmentally friendly, 99% recyclable by weight
- Reliable operation, easy installation and servicing
- Required minimal area, only 70-90m² for a single Z20 unit, 15.5kWp combined output (<6m²/kWp)
- Packaged equipment, minimizing balance-of-system cost



Engineering Data

Data		Units	Z20
General	Number of modules (dishes)	EA	2
	Total aperture area	m^2	22
	Tracking technology	2-axis	
	Azimuth range	deg	0-360º
	Elevation range	deg	0-90º
	Tracking control	Sensor-less closed loop	
Electricity	Peak electrical power	kWp	4.5 (*)
	Operating voltage	VDC	160-230
Thermal	Peak thermal power	kWp	11 (*)
	Fluid	Water or coolant	
	Maximum supply temperature	deg C	100
	Nominal flow (both modules)	l/min	12
Physical Dimensions	Operating wind speed	km/h	40
	Permissible wind speed	km/h	160
	Weight	kg	1,500
	Height in stowed position	m	4.53
	Height in operation	m	4.10
	Depth	m	3.76
	Width	m	7.58
Compliance	IEC 62108, CE		
Inverter	Mounting ready		

Notes: (*) Tested at 1kW/m² irradiance. Allowing up to 4% yield losses, due to shading (northern latitude 200-400)
Data is subject to changes

ZENITHSOLAR
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5 Habarzel Blvd. P.O.B. 8627 Qiryat Gat 82000, Israel

The Light-guide Solar Optic (LSO)

www.morgansolar.com

What makes the Sun Simba different is its unprecedented solar concentrator, the patented **Light-guide Solar Optic (LSO)**.

The LSO is a thin optical structure made from simple acrylic and glass components that internally traps and redirects sunlight, concentrating it onto a small, high efficiency photovoltaic cell attached at the optic's centre. Designed to capture and concentrate sunlight – not the image of the sun – the need for focal depth and the related bulky enclosures of competing Concentrated Photovoltaic (CPV) systems are eliminated:

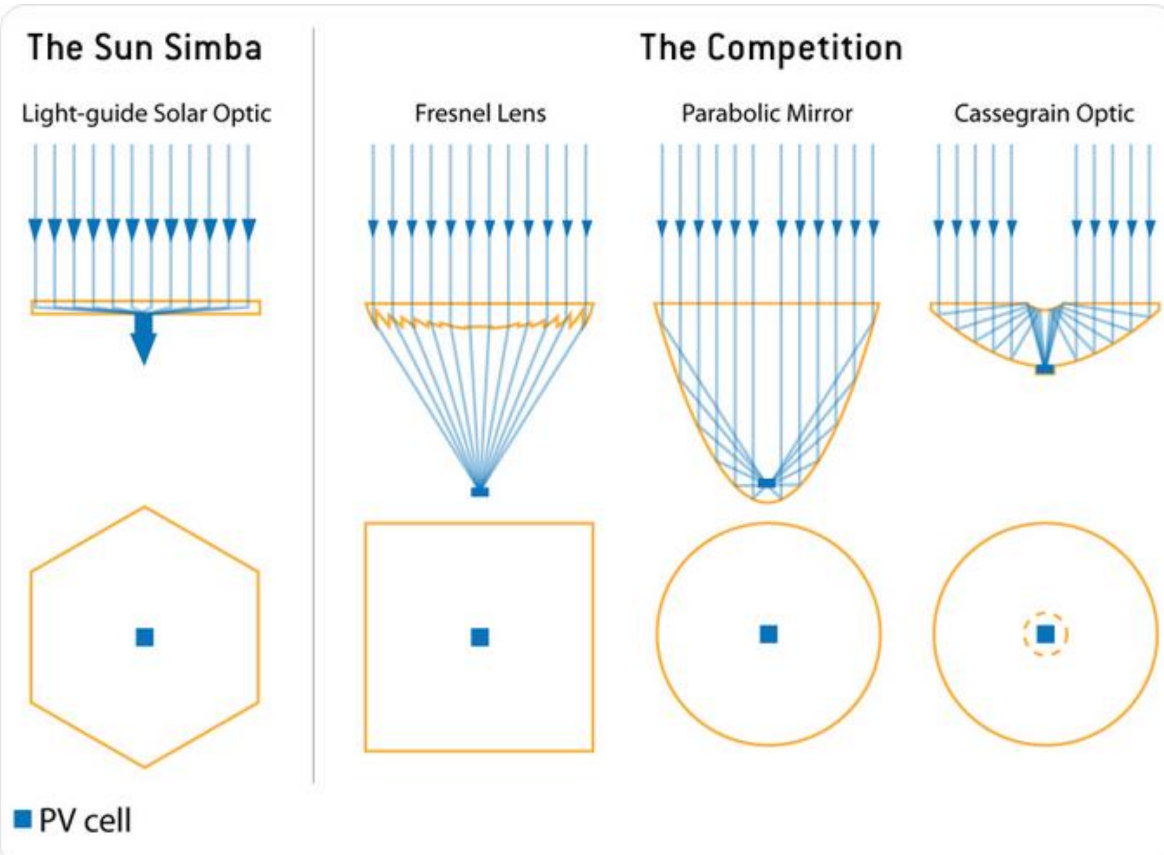


Figure 1: *Morgan Solar's LSO vs. Competition Optics: Our LSO has a lower profile and uses less material than any other concentrating system, with equivalent or better concentration factors and angular acceptance.*

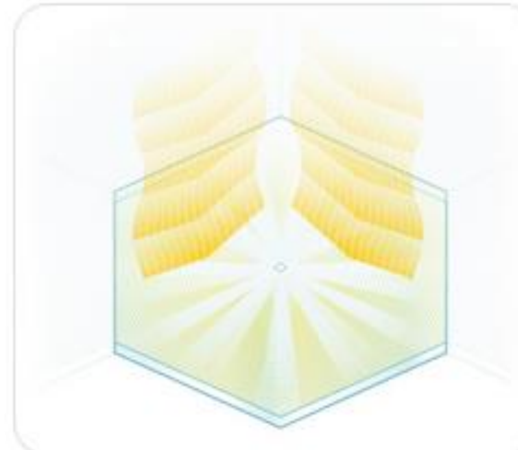


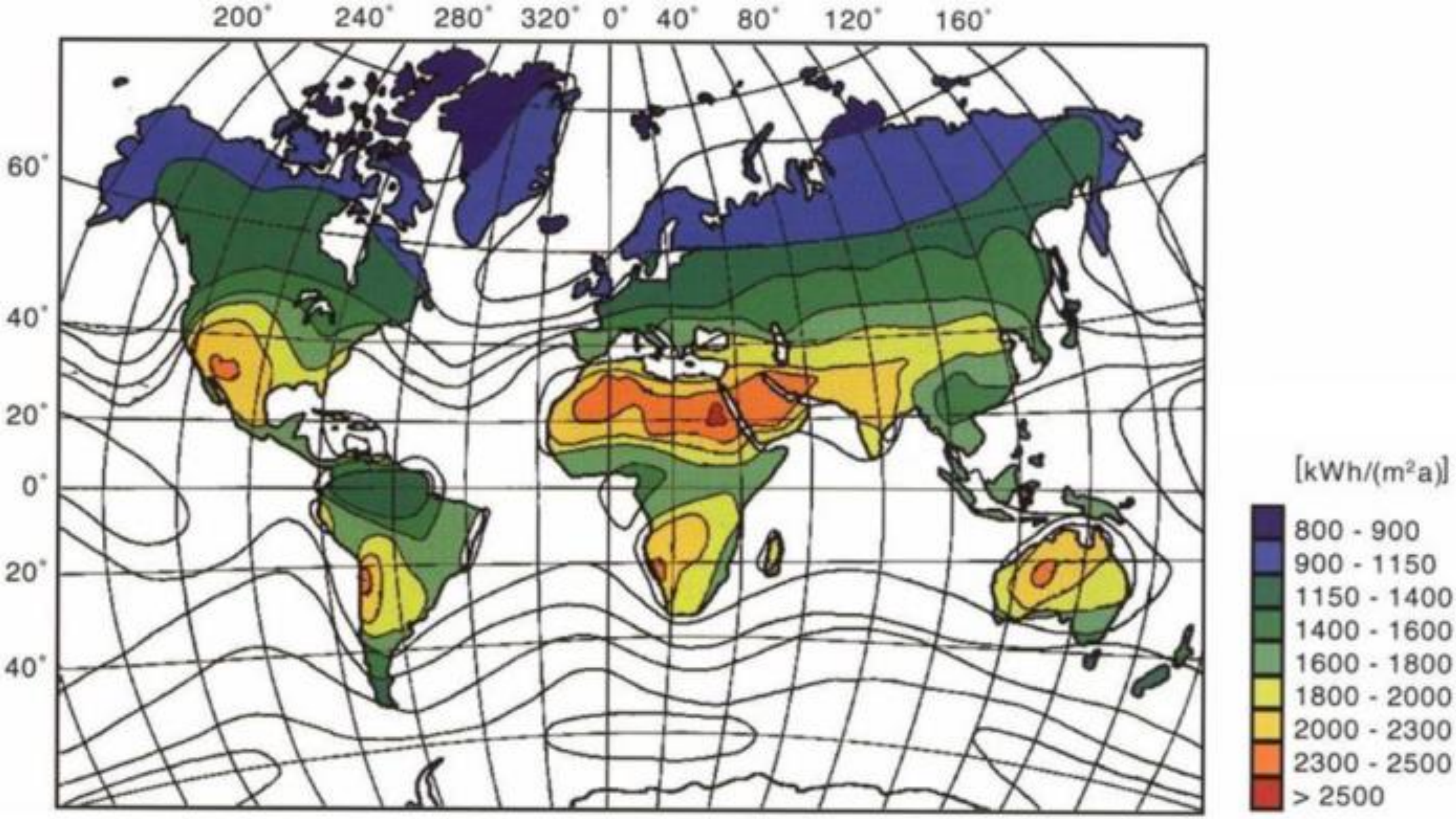
Figure 2: *Light striking the top of the LSO is trapped and transported inside the optic to a high efficiency, multi-junction PV cell located at the optic's centre.*

Advantages of the LSO

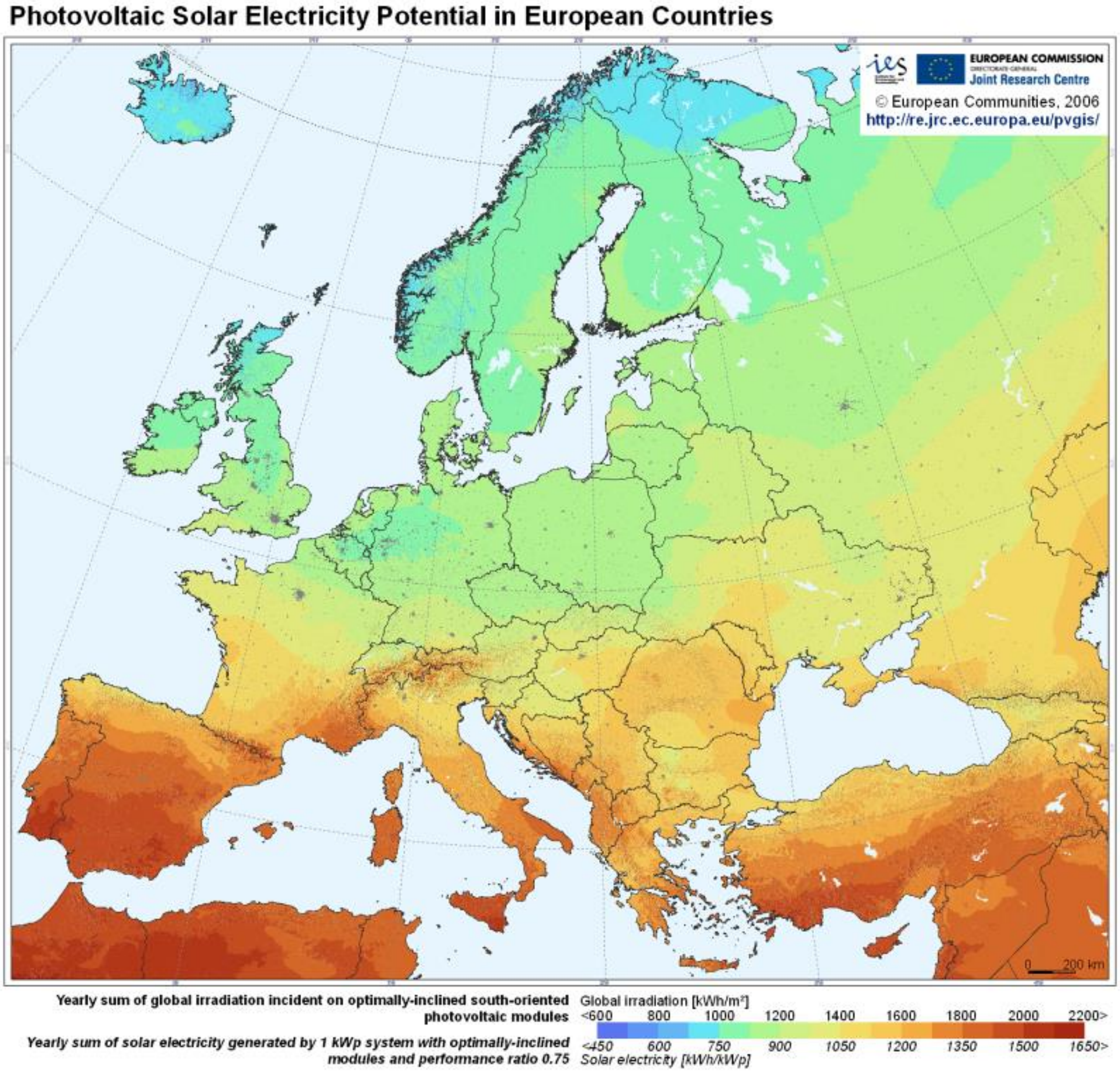
- concentrates sunlight by up to 1000 suns with higher concentrations possible
- eliminates the bulkiness of existing CPV systems
- not affected by thermal expansion
- is extremely low cost
- light-weight and rugged
- easy to manufacture
- no toxic or exotic materials, 100% recyclable

This system does not use mirrors or lenses. **This is something totally new, different, and better.**

World Solar Radiation

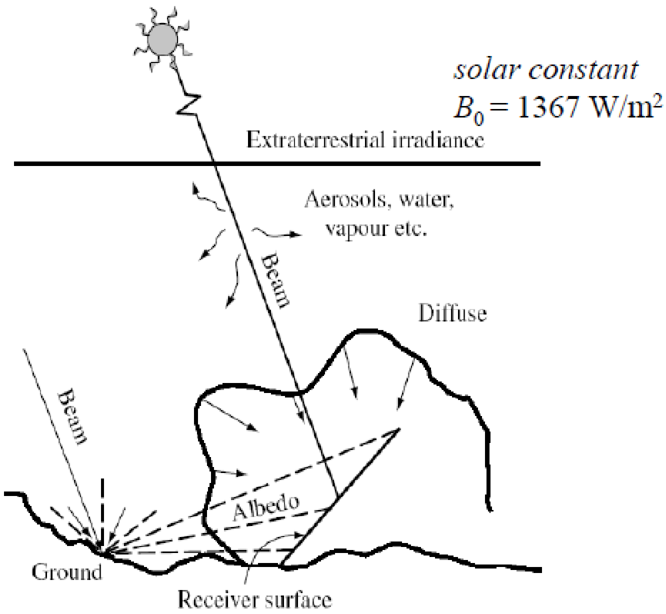


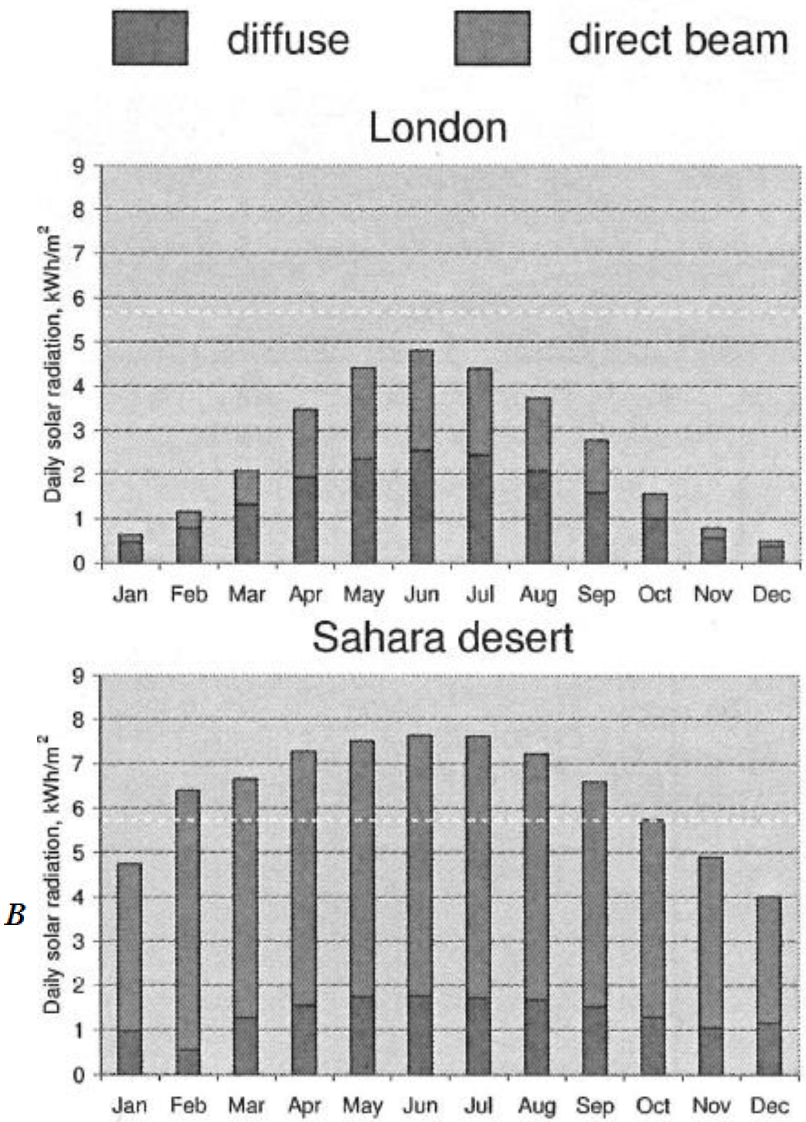
Europe Solar Radiation



Direct versus Diffused Solar Radiation

Irradiance means density of power falling on a surface, and is measured in W/m^2





beam radiation, made up of beams of light that are not reflected or scattered - ***B***

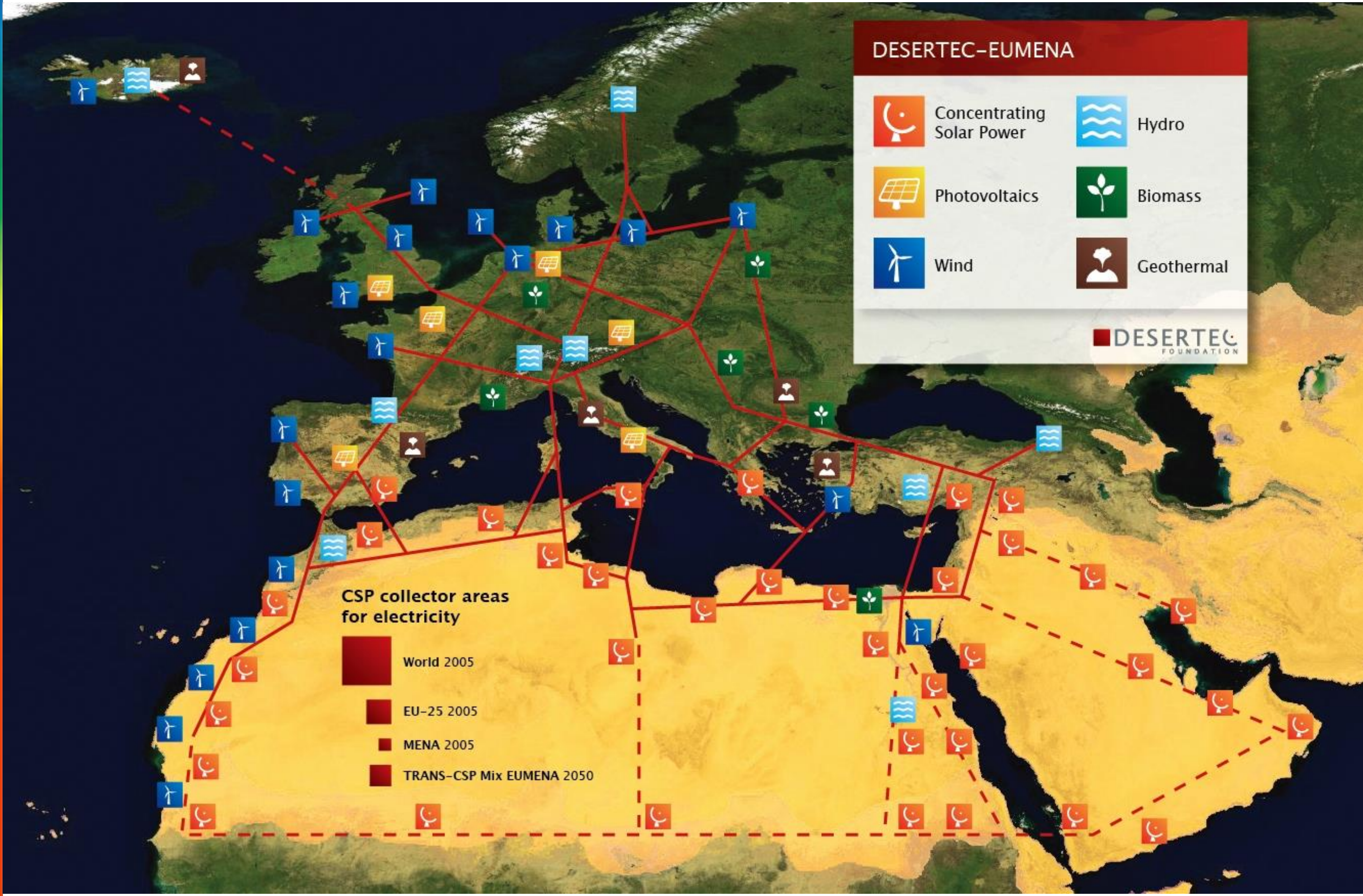
diffuse radiation, coming from the whole sky apart from the sun's disc- ***D***

albedo radiation is radiation reflected from the ground **-** ***R***

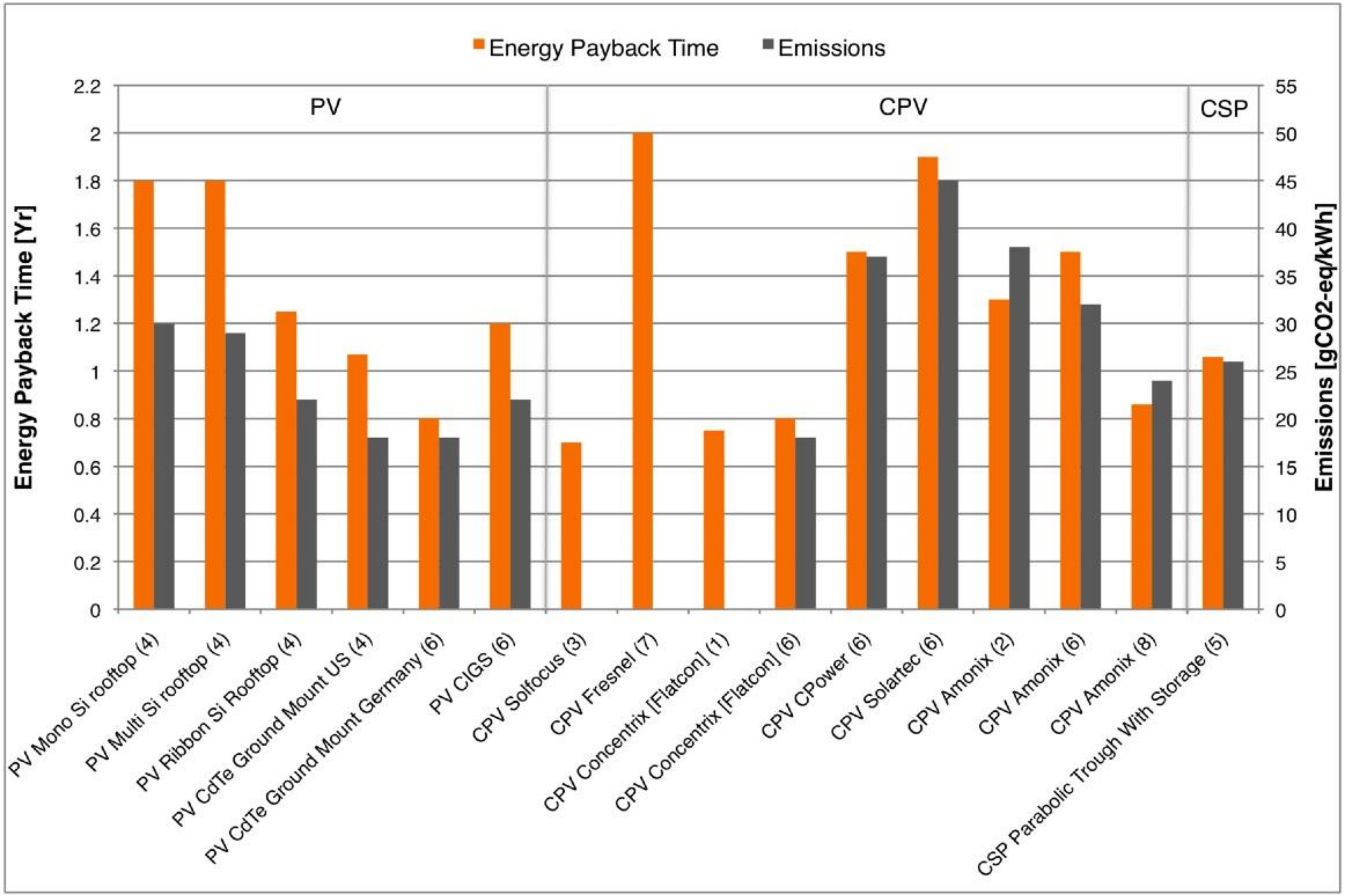
global radiation (direct + diffuse + albedo). $G = B + D + R$

Desertec = 400 billion euros ($514 billion)

http://www.desertec.org/

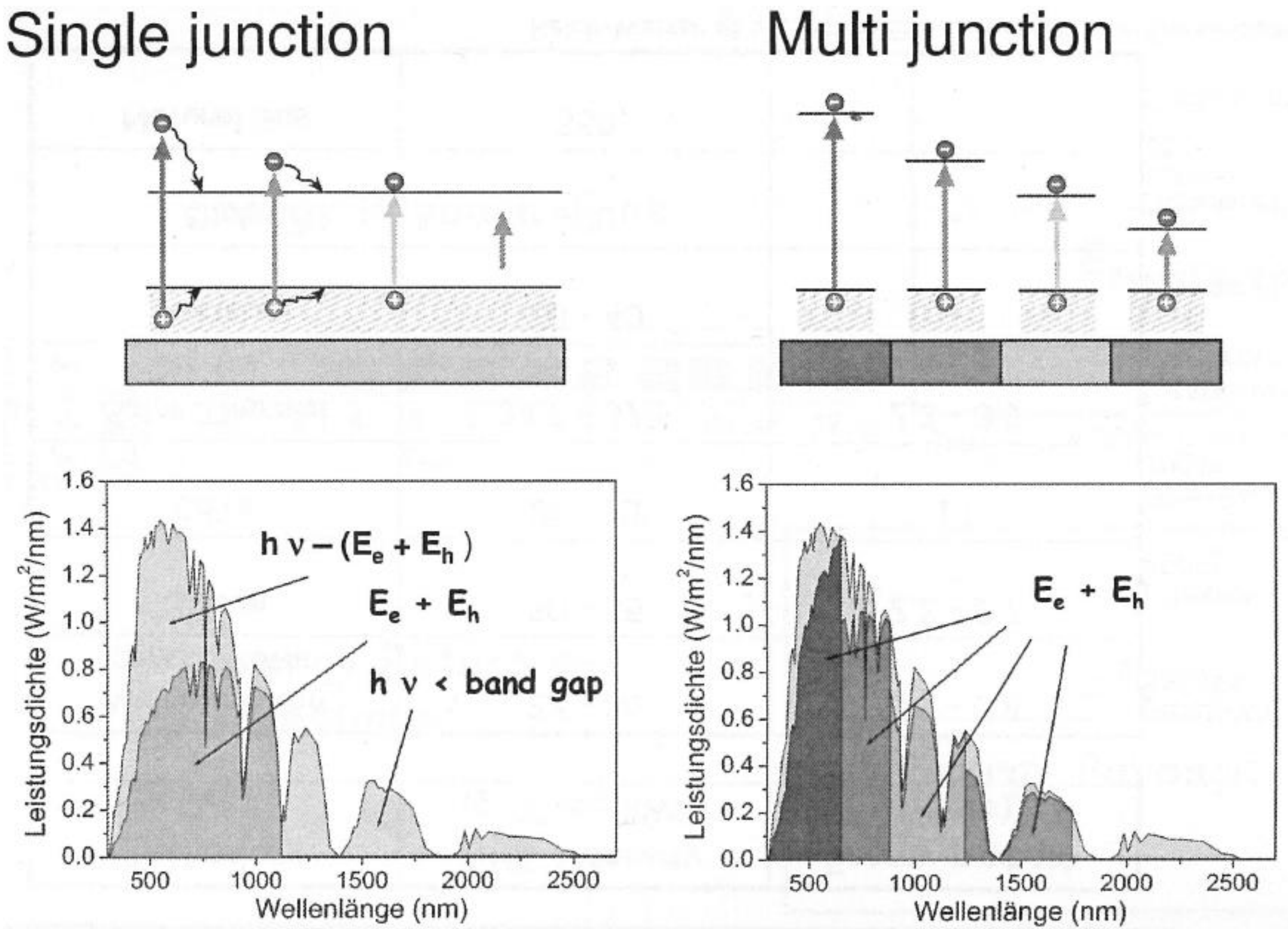


Energy Payback Time and GHG Emissions



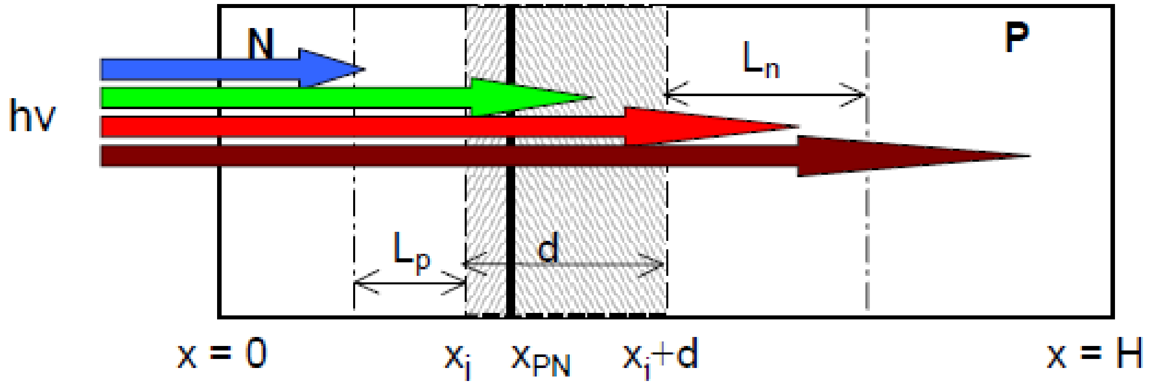
http://www.greentechmedia.com/articles/read/an-assessment-of-the-environmental-impact-of-cpv

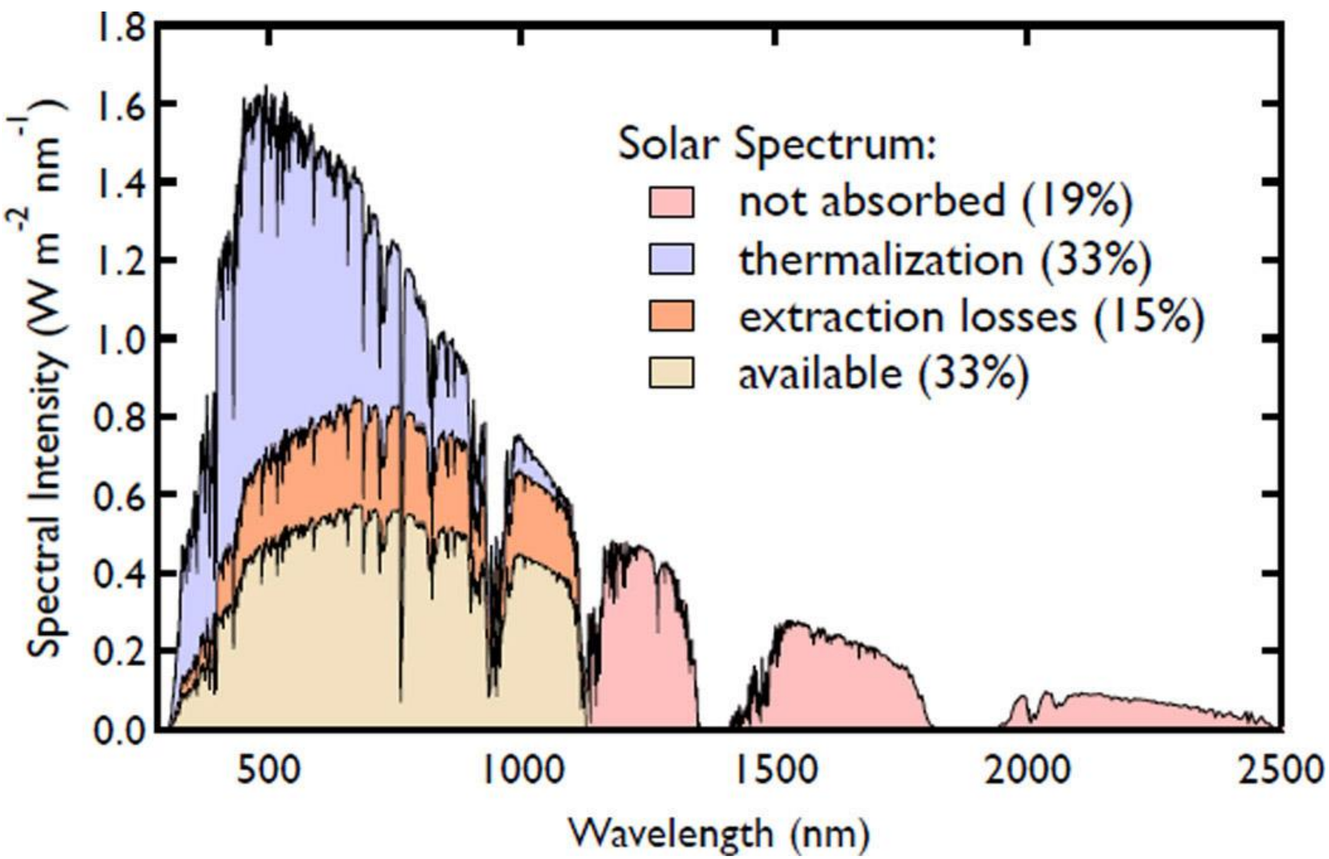
Solar Cells for Concentrators



Solar Cells for Concentrators

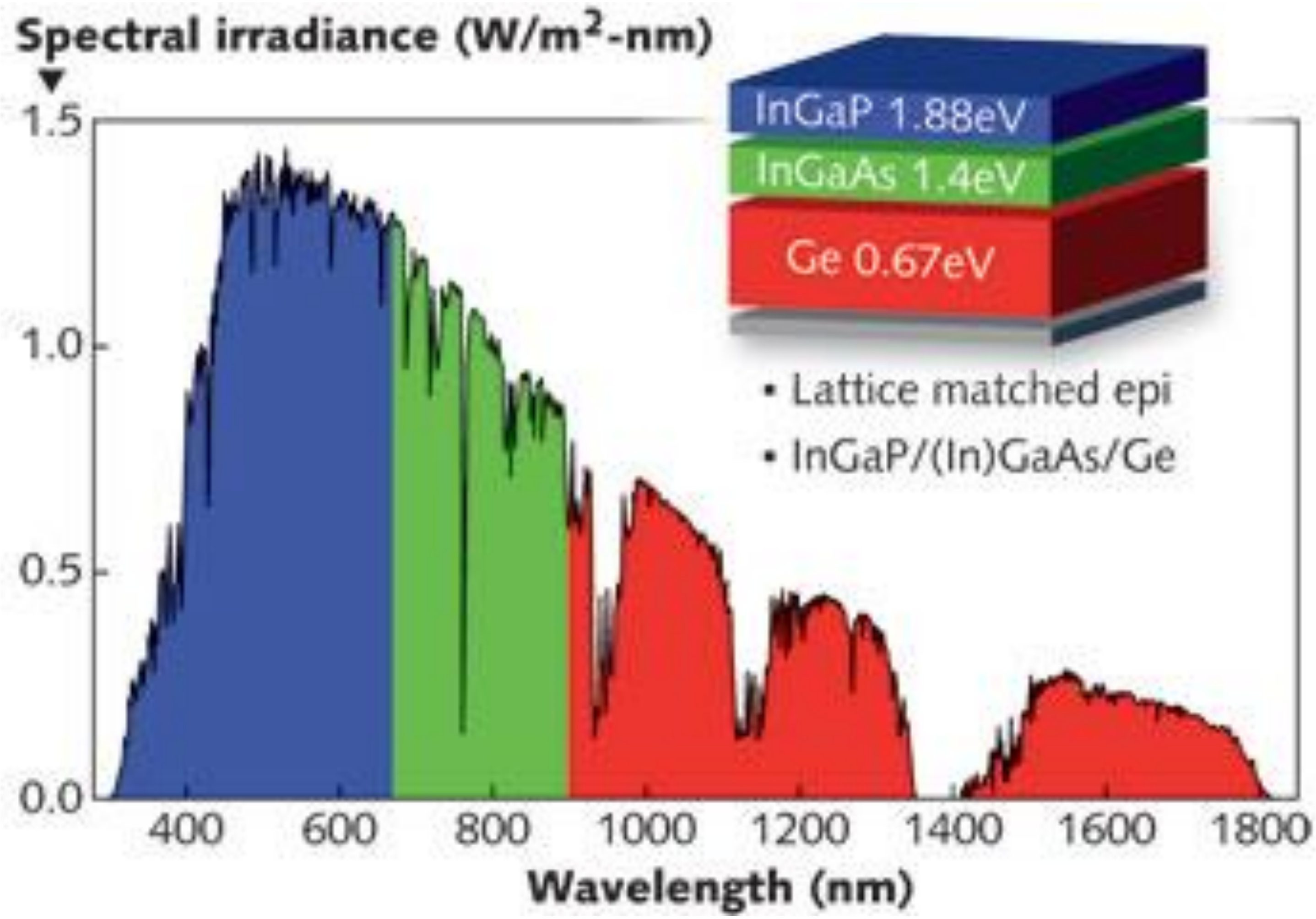
- Single-junction





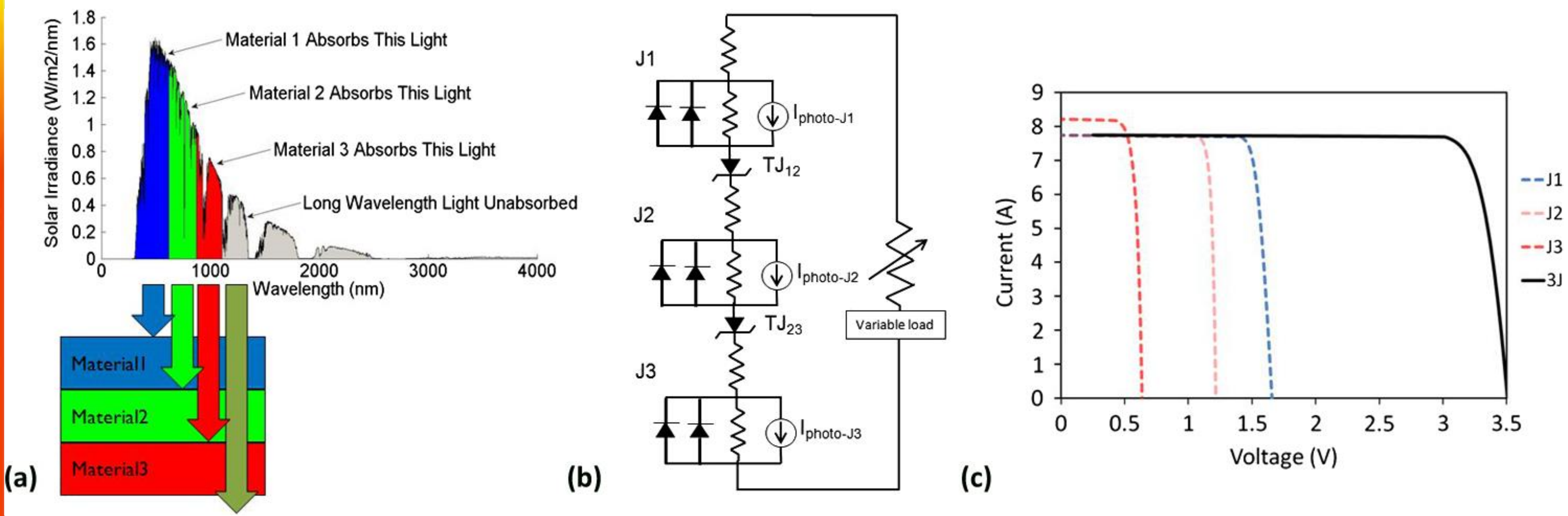
Solar Cells for Concentrators

- Multi-junction



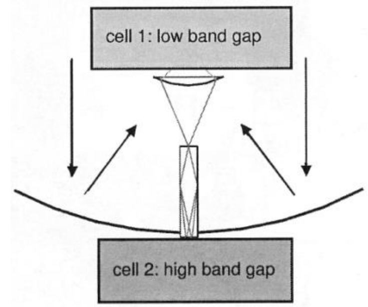
Monolithic and Non-Monolithic Concept

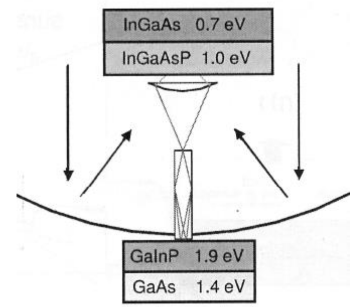
- Monolithic concept of multi-junction solar cells
  - Lattice-matched solar cells
  - Grading the lattice constant
  - Wafer bonding
  - Current matching

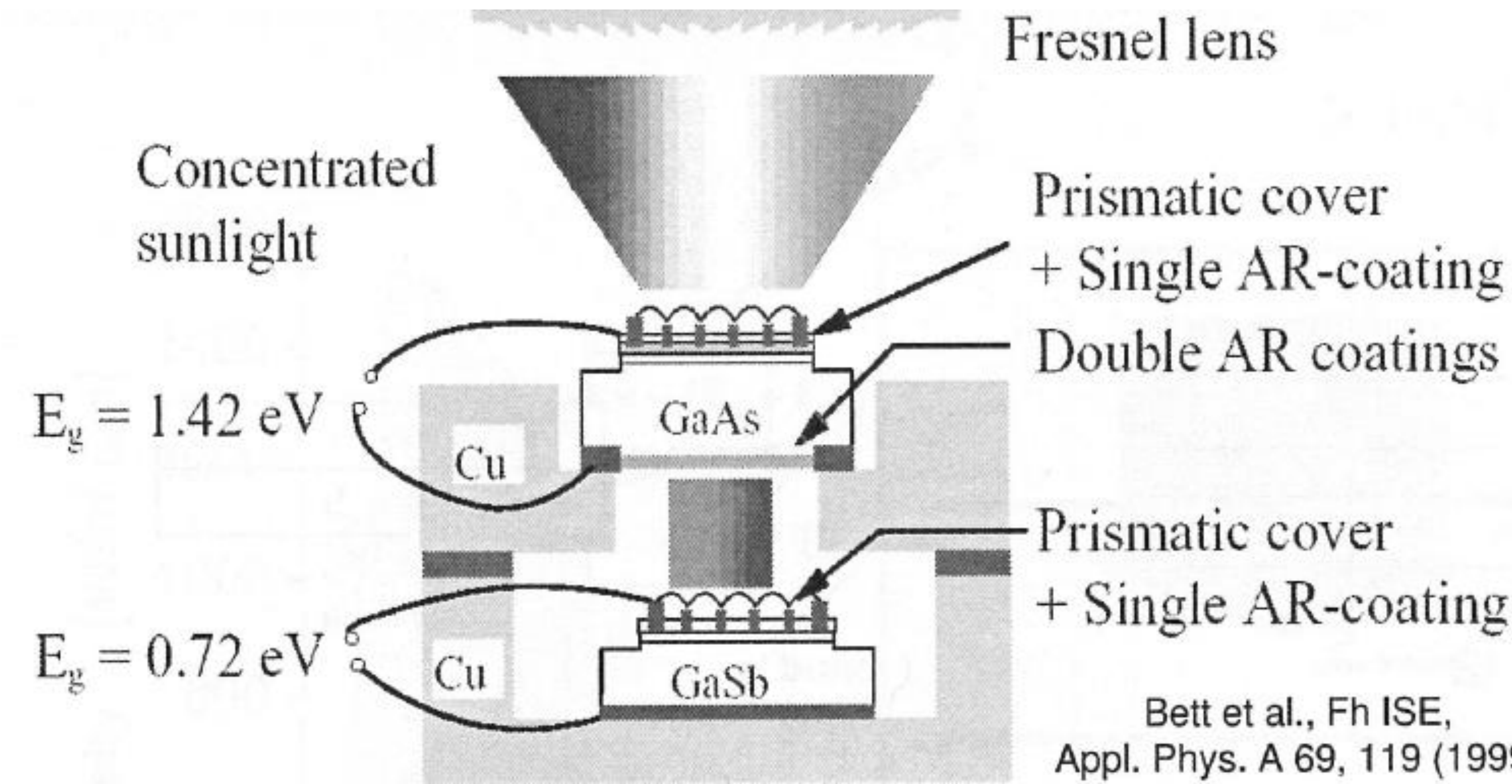


Monolithic and Non-Monolithic Concept

- Non-monolithic concept of multi-junction solar cells
  - Spectrum splitting
  - Mechanical stacking



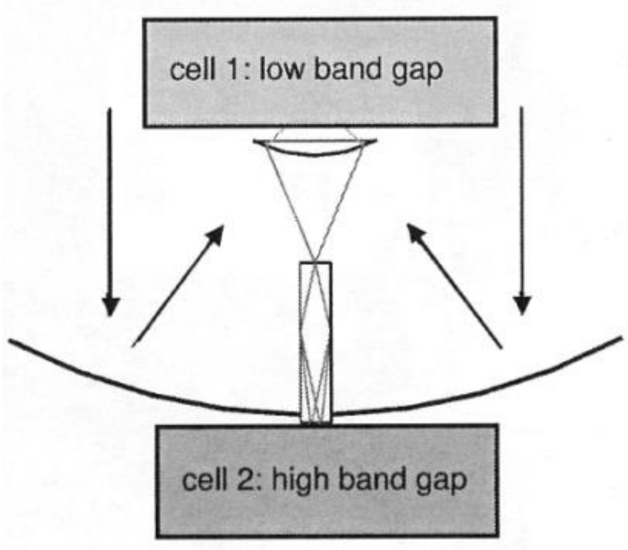




Bett et al., Fh ISE,
Appl. Phys. A 69, 119 (1999)

Mechanically Stacked Solar Cells

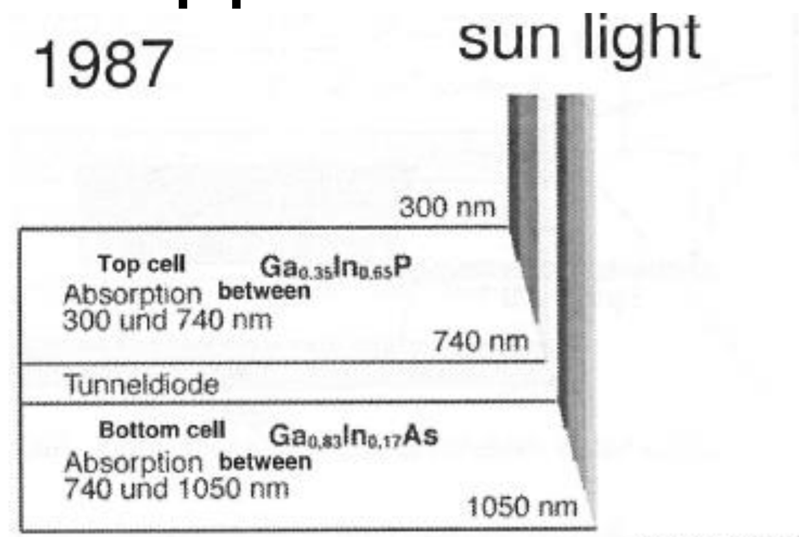
- Advantages
  - No current-matching required
  - No lattice-matching required
  - Each layer optimized separately to produce maximum power



- Disadvantages
  - Processing challenges
  - Expensive (2 wafers)
  - Heavy
  - Multiple metal interconnects shadow part of the device

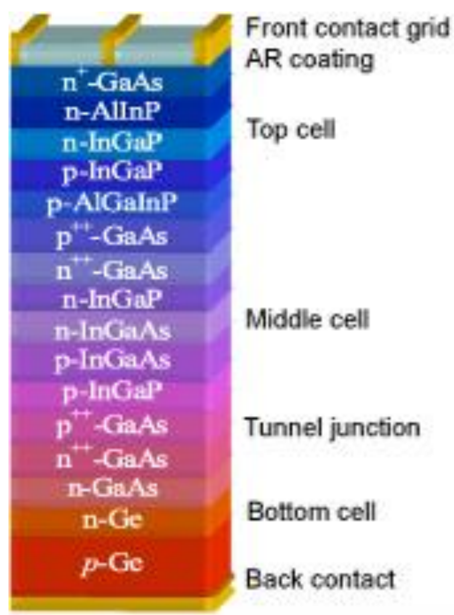
Monolithic Approach

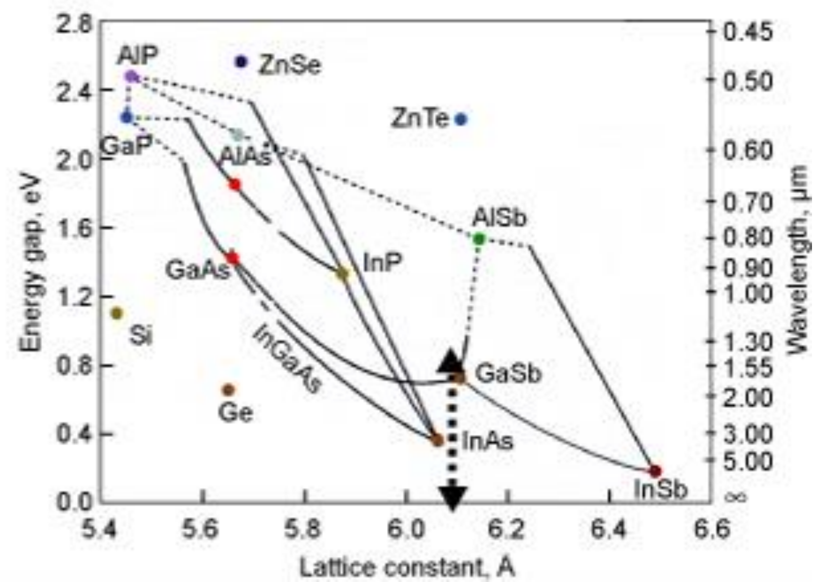
- First tandem solar cell (1987)



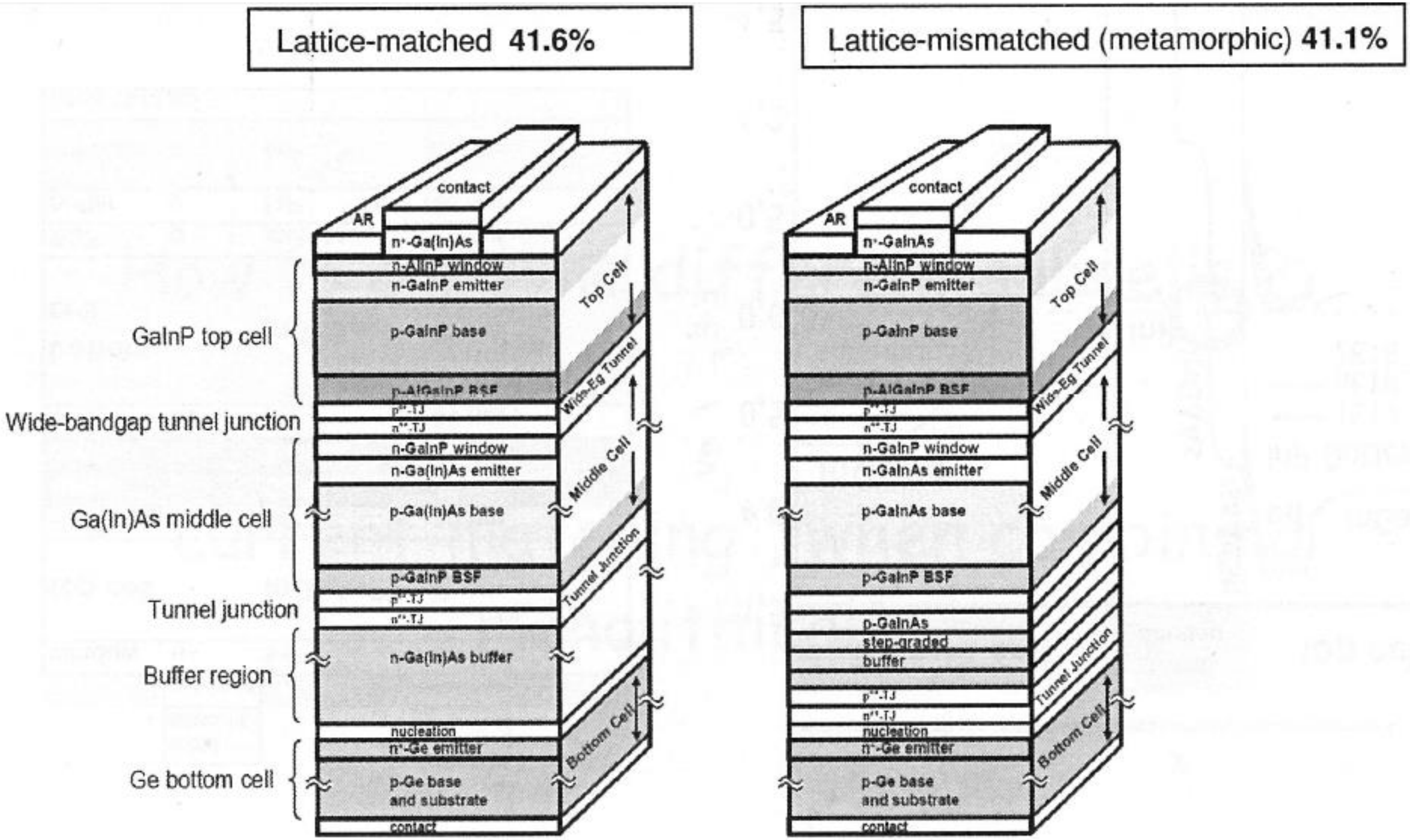
Source: NREL

- 3 junction solar cell





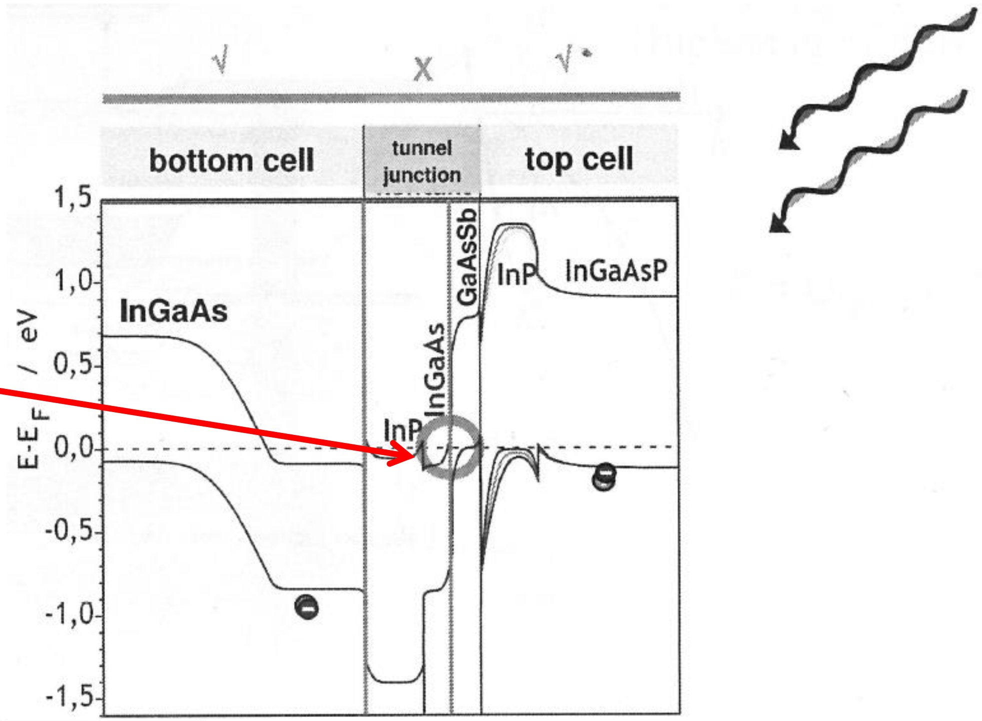
Record Multi-Junction Solar Cells

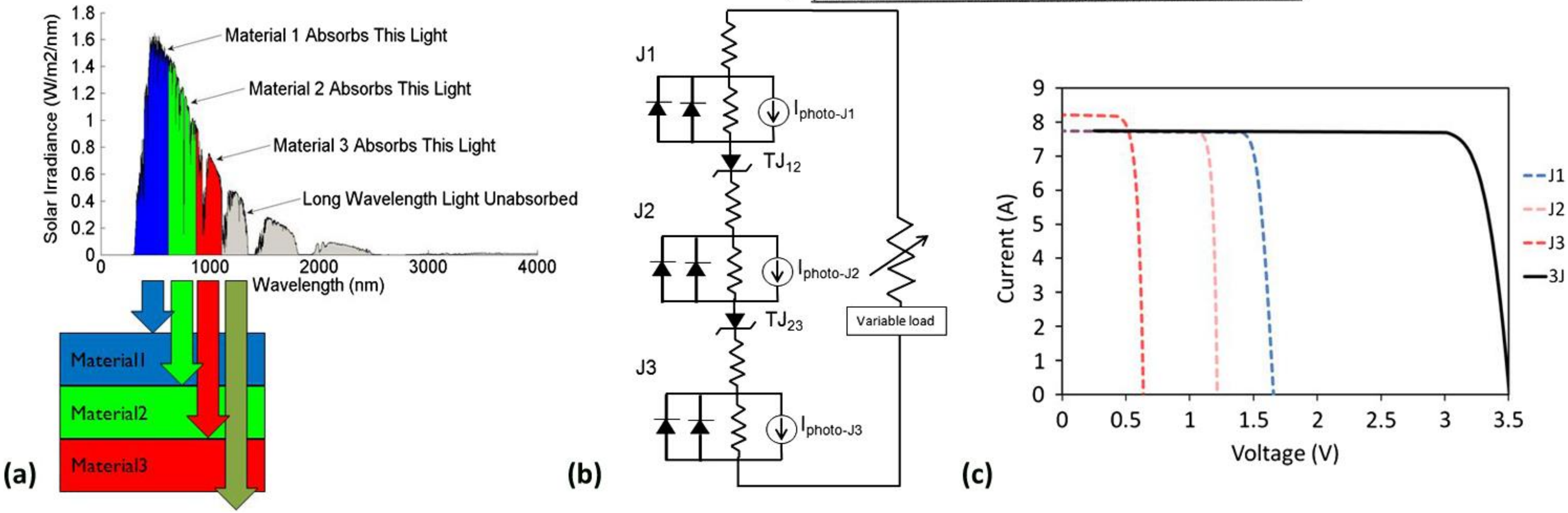


R.R. King *et al.* Appl. Phys. Lett. 90 (2007) 183516

Structure of Tandem Cell

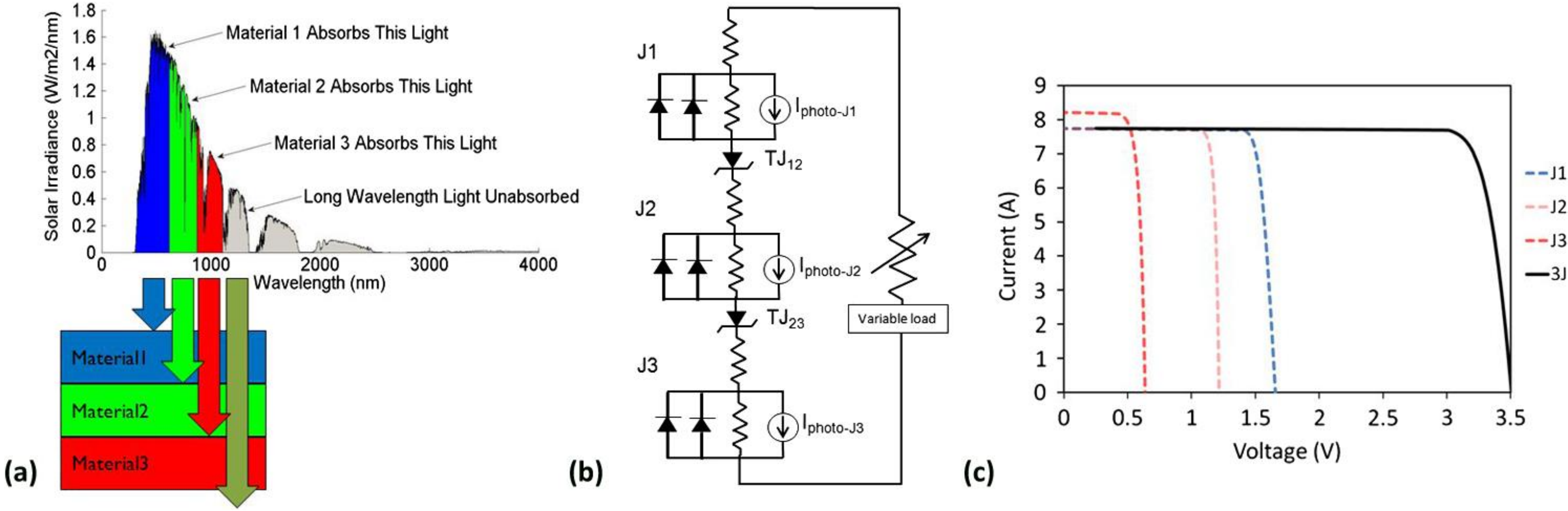
- Band gap diagram
  - Avoid non-desirable recombination!!!





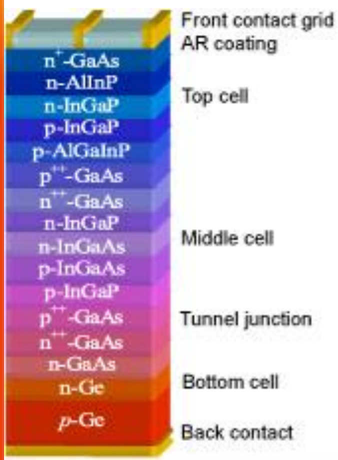
Characterization of Tandem Cell

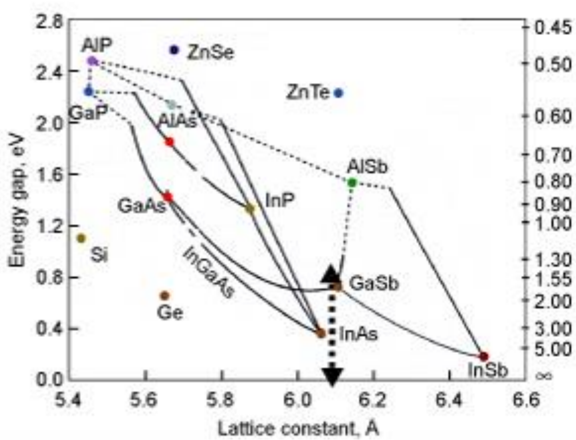
- Light sources with appropriate wavelength

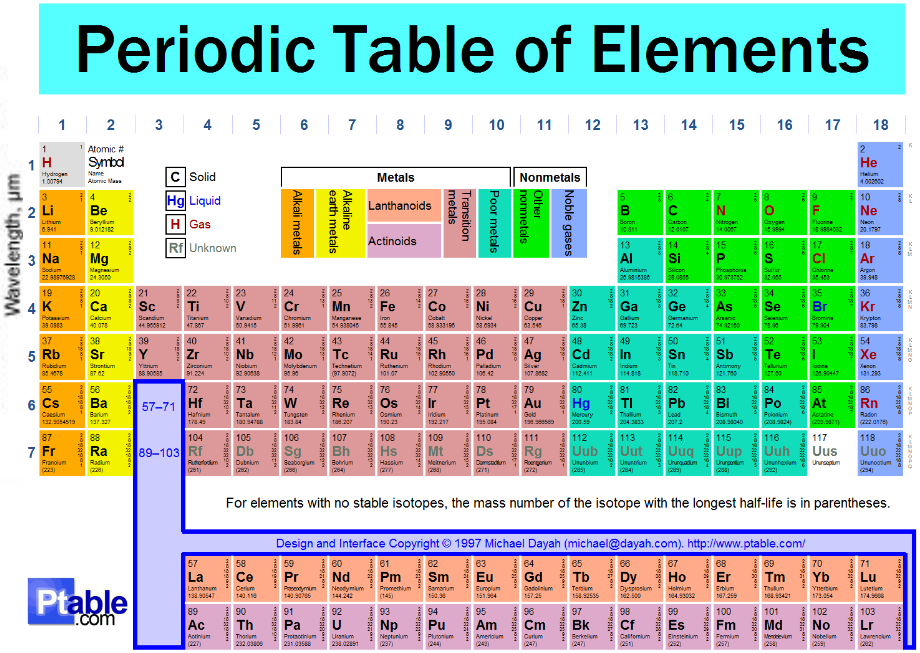


Elements for These Structures

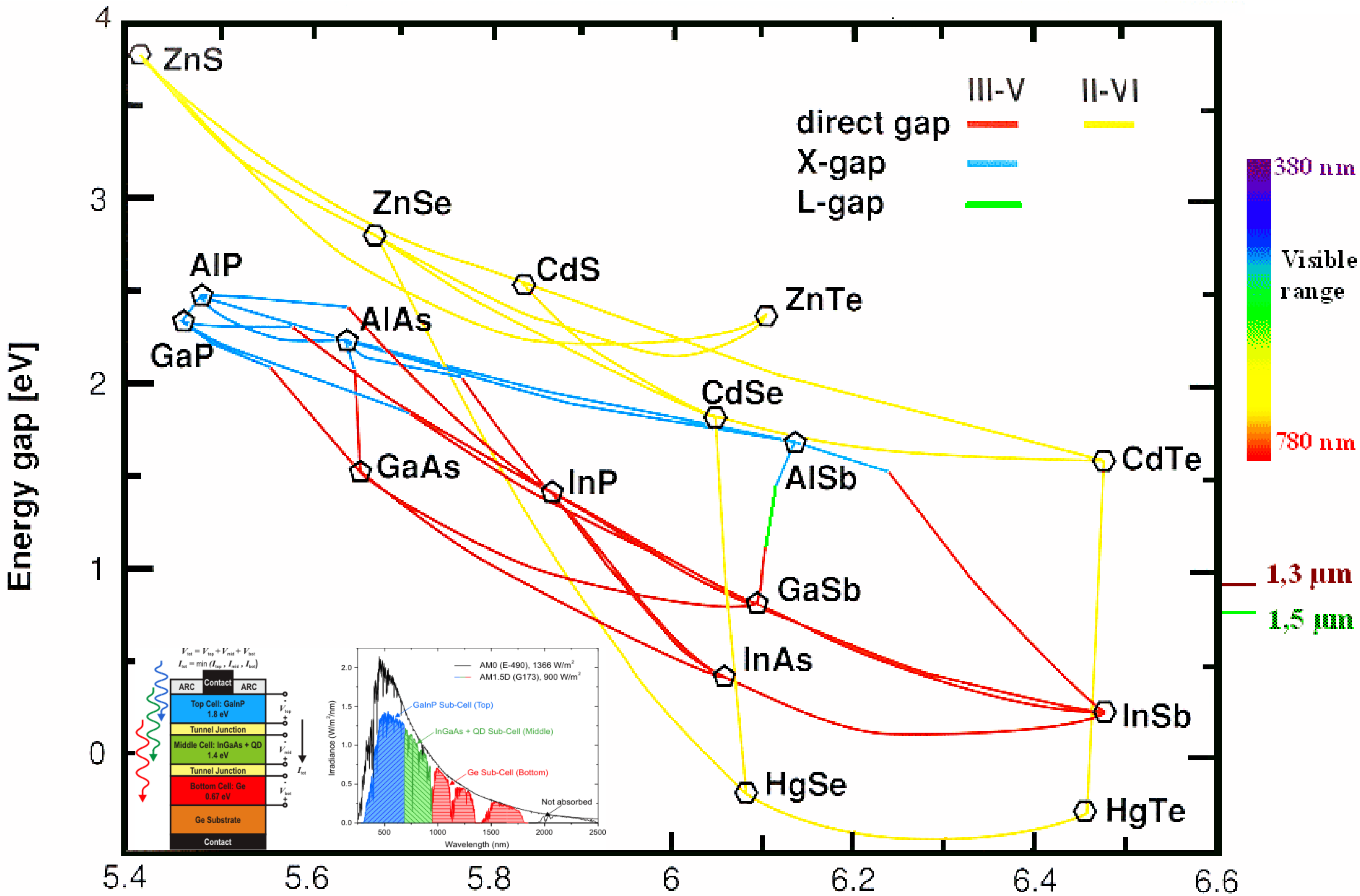
- Alloys from a-Si, c-Si, Ge
- III-V because
  - Low defect density (recombination in pure material very low)
  - Properties tunable in a wide range (band gap engineering, reproducible preparation on atomic scale)
  - Direct band gaps (high absorption coefficient)







Band Gap Engineering



SOLAR ENERGY APPLICATION SYSTEMS

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