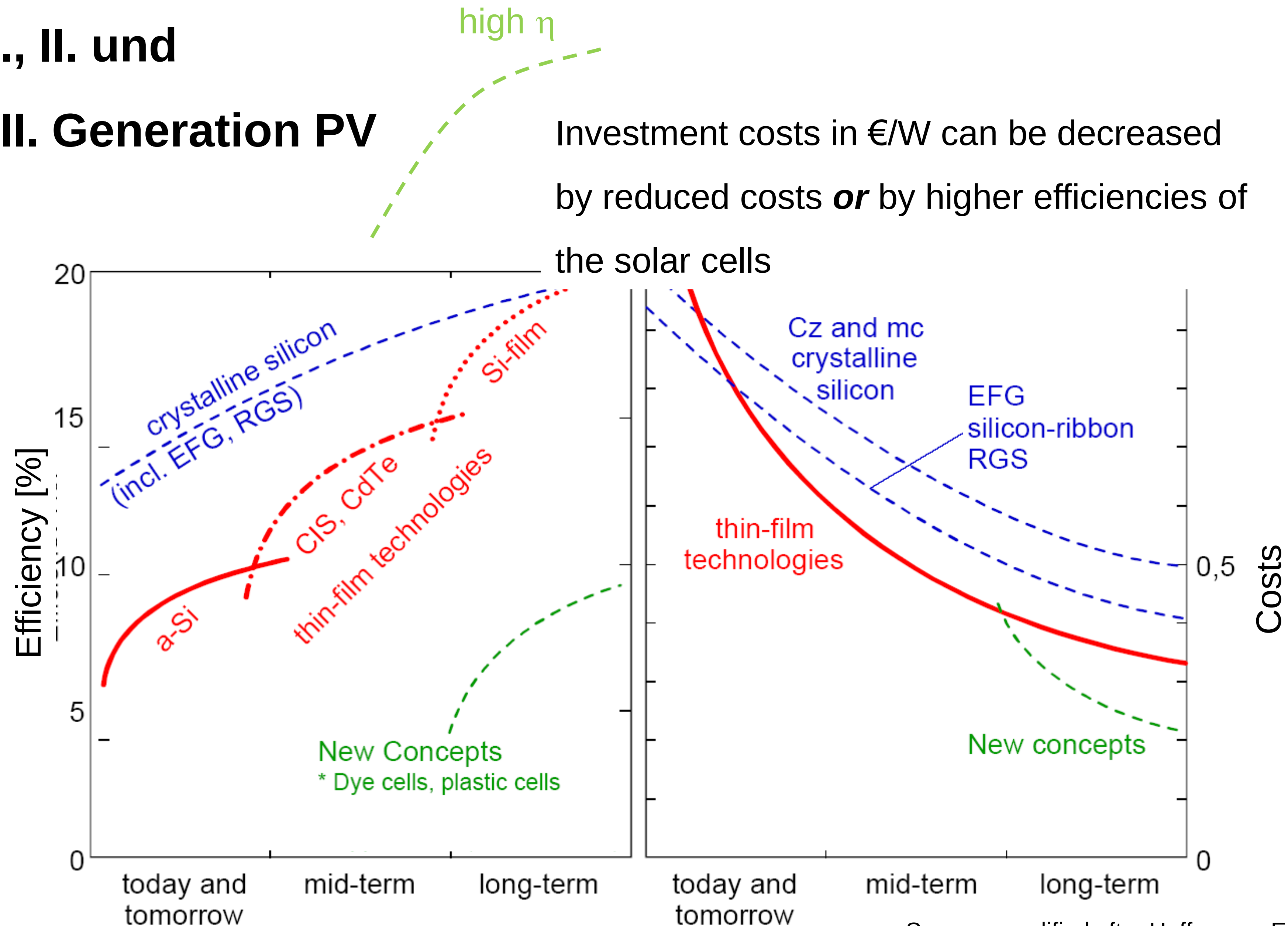
# Outline

# I., II. und

# III. Generation PV

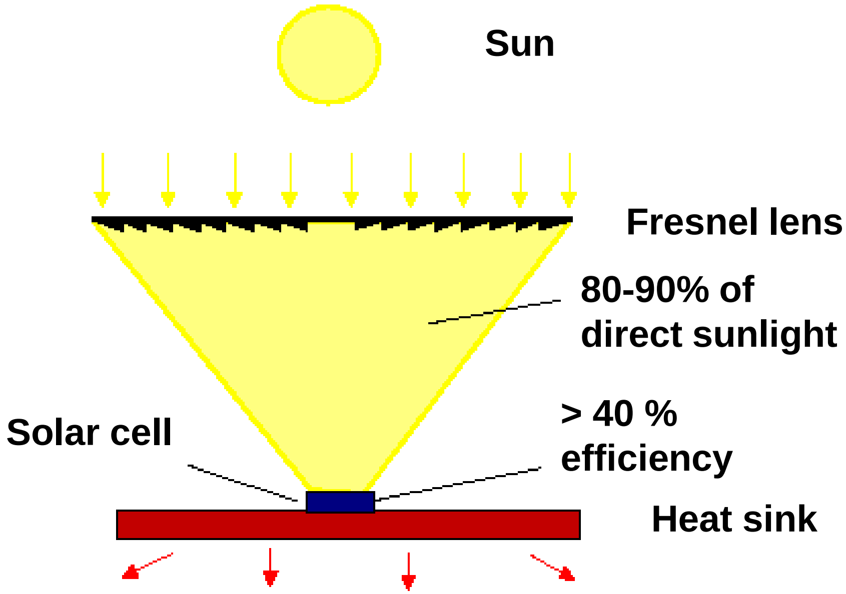
Investment costs in €/W can be decreased by reduced costs ***or*** by higher efficiencies of the solar cells




Source: modified after Hoffmann , EPIA

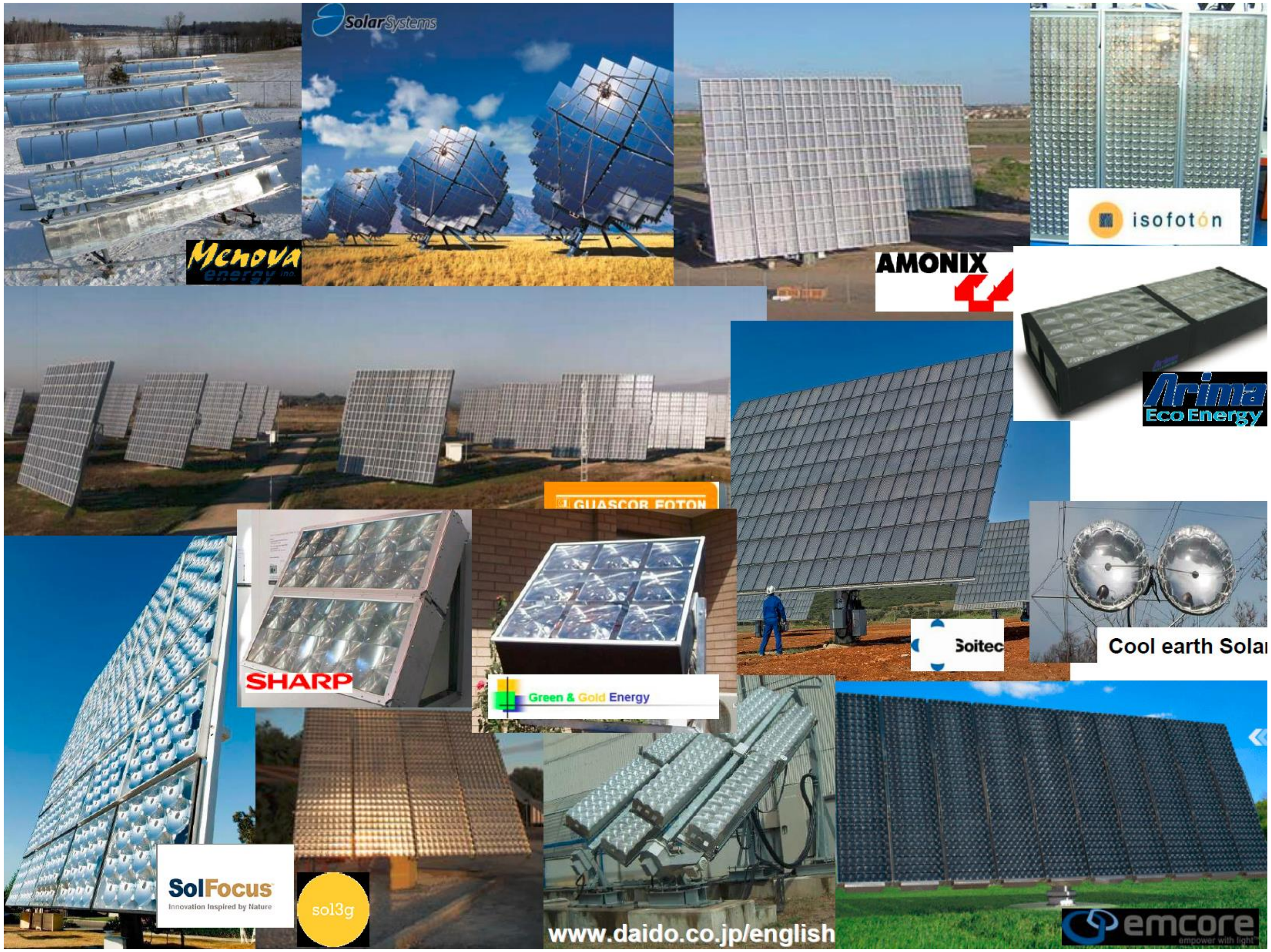
# Concentrator Photovoltaics (CPV)

Idea: use very efficient (and expensive) small solar cells and concentrate the light with low cost optics




- Tracking is needed as only direct sun light can be focused!

# Impressions of different technologies



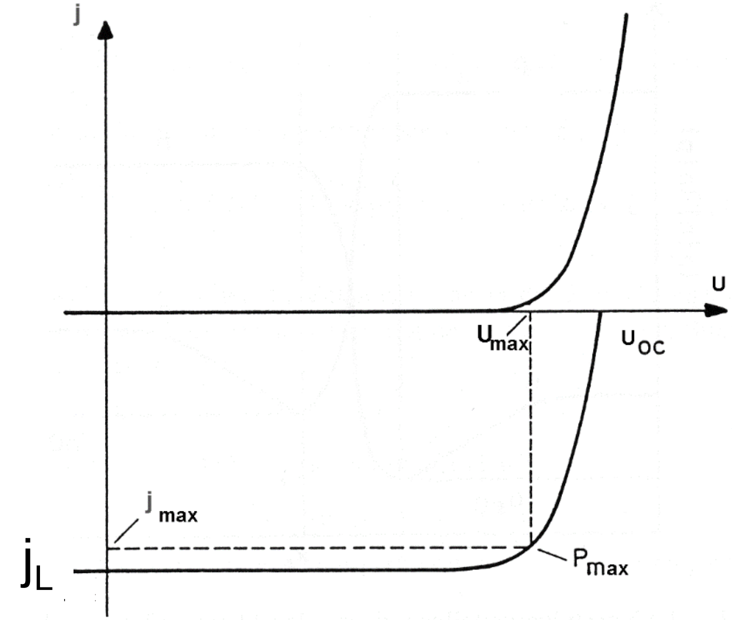
# Outline

# Reminder: I-V Characteristics of Solar Cells

Maximum electrical power:

$$P_{\max} = U_{\max} I_{\max} =$$ Area of the largest rectangle in a working point of the I-V-char.

$$U_{\max} < U_{OC} = \frac{kT}{e} \ln\left(\frac{I_L}{I_s} + 1\right) \approx \frac{kT}{e} \ln\left(\frac{I_L}{I_S}\right)$$



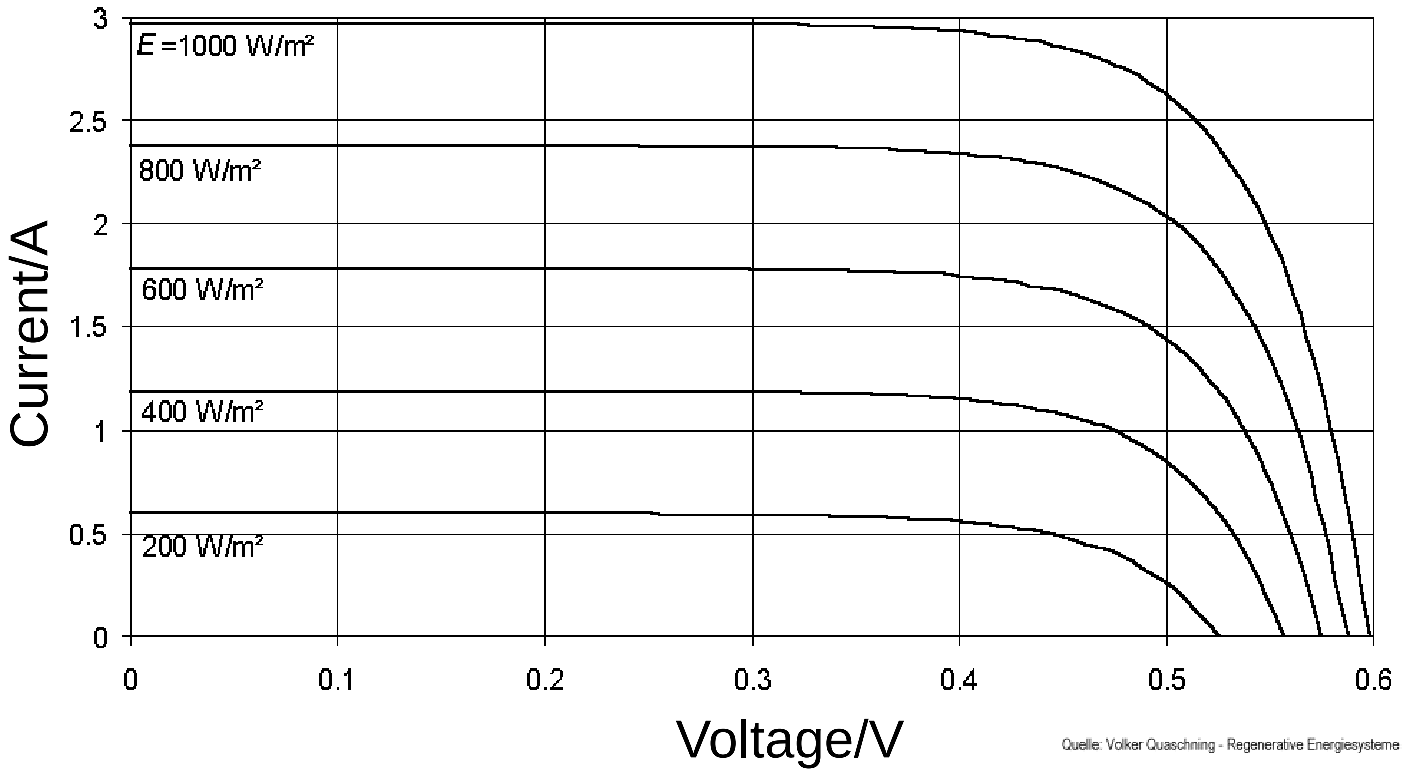

$$I_{max} > I_L = j_L \cdot A$$

Negative absolute current values!

$$FF = \frac{U_{\max} I_{\max}}{U_{oc} I_{sc}}$$

Typical values for FF are 0.75-0.85

# The role of the irradiance

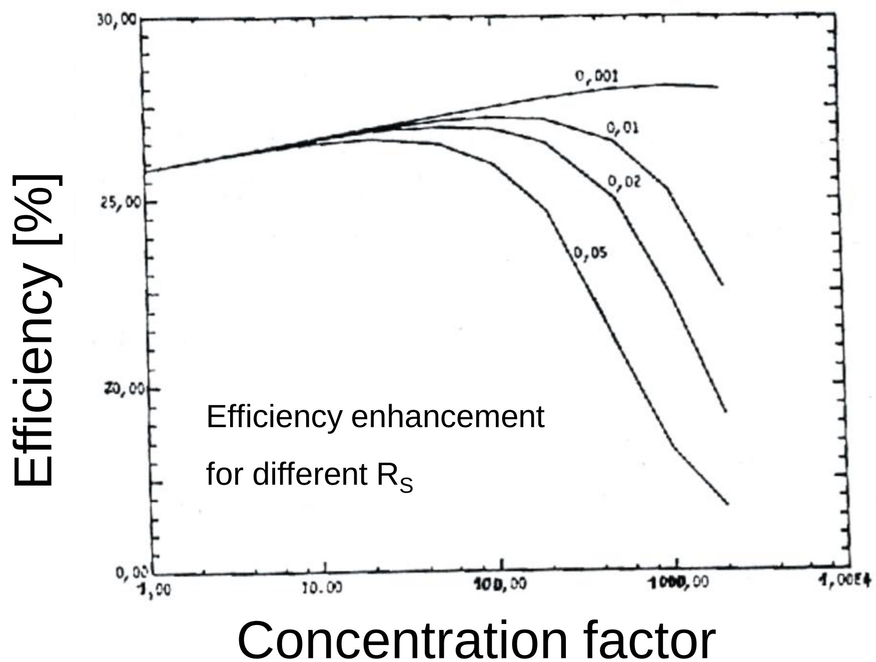



Since the solar cell is regarded as a generator , the I-V-curves are often mirrored at the U-axis.

- photocurrent varies proportional to the irradiance

- open circuit voltage varies logarithmically with the irradiance

# Concentrator PV: Enhanced efficiency




Let C be the concentration factor

$I_L$ is proportional to C

$$U_{OC} = U_T \ln\left(\frac{I_L}{I_0} + 1\right)$$

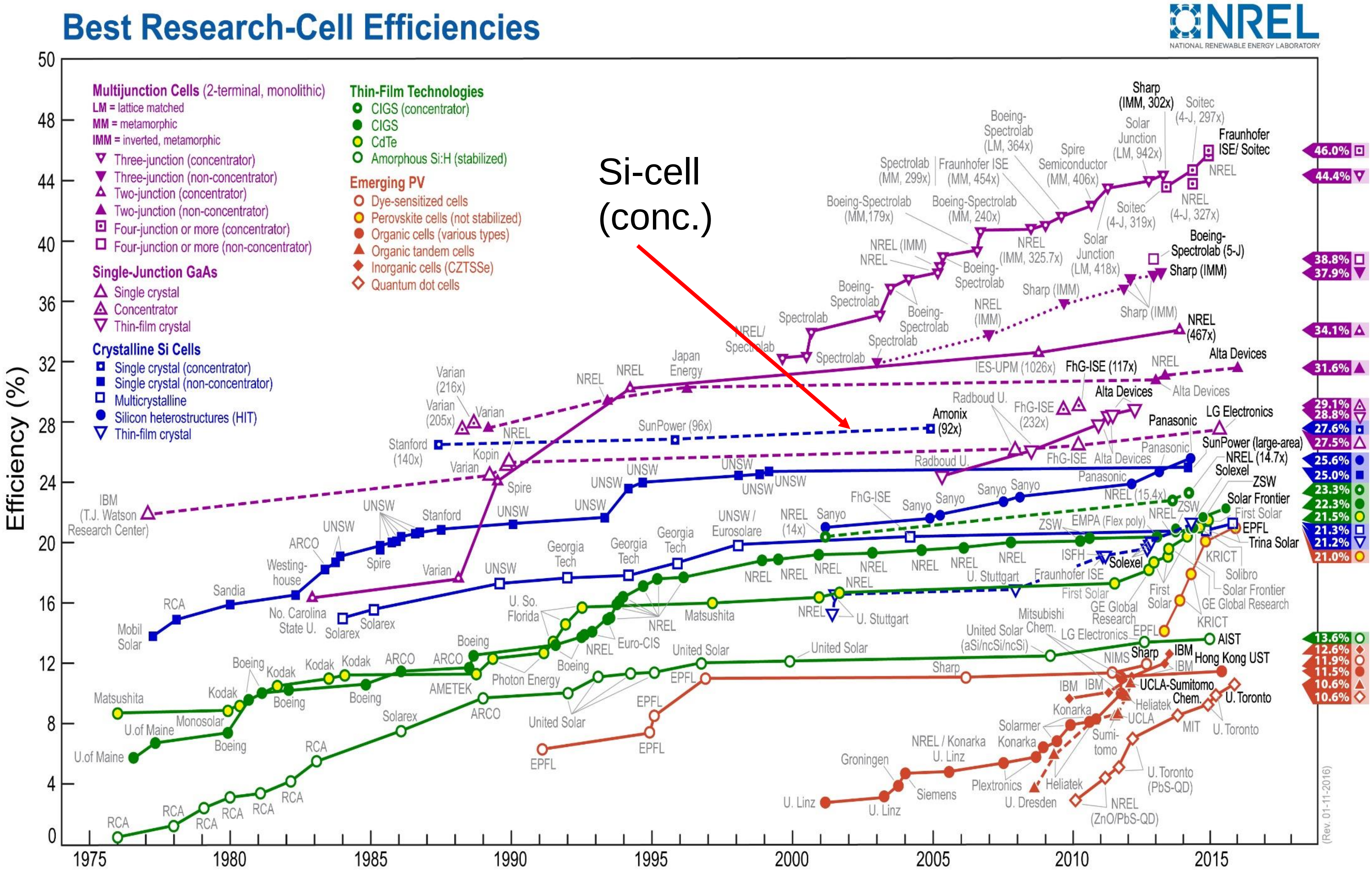
Efficiency without concentration:

$$\eta = \frac{I_L U_{OC} * FF}{P_L}$$

Efficiency with concentration:

$$\eta = \frac{C I_L U_{OC}(C) * FF}{C P_L}$$

→ Efficiency grows with the logarithm of the concentration factor, as long as temperature effects and the series resistance do not play a role






KIT Karlsruhe Institute of Technology

# Outline

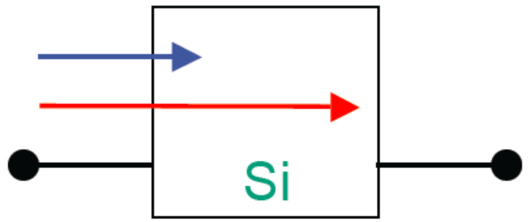
# Reminder: Spectrally dependent energy harvesting with a single cell

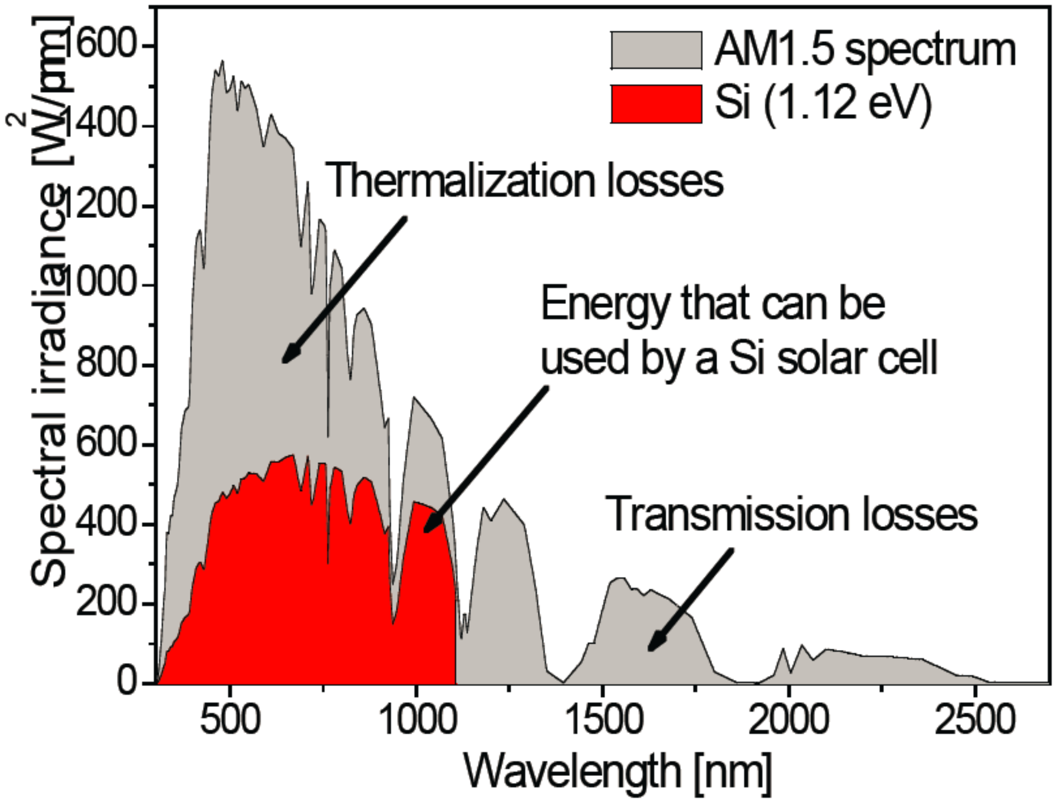
For Silicon:

(AM1.5g, 1000 W/m², 25°C)

$\eta_{max, theo}$ = 28 %

Lab cell = 24 %




Source: E. Weber, FhG ISE

# Multijunction cells for efficiency enhancement

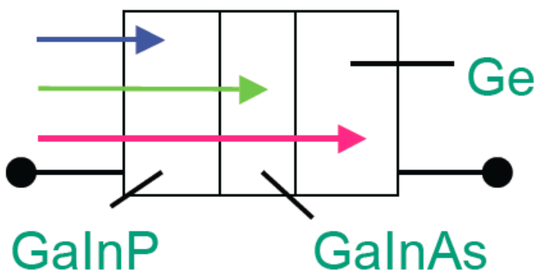
For triple-junction concentrator cells:

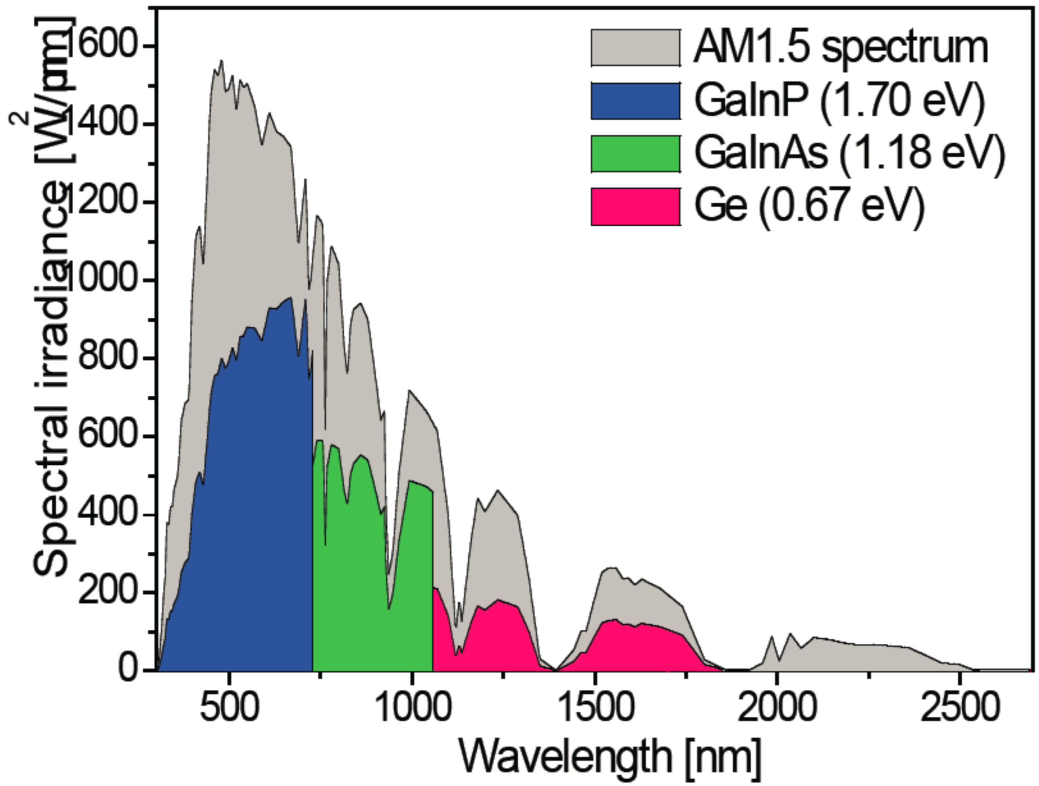
$\eta_{max, theo}$ = 61 %

(1000xAM1.5d, 1000 W/m²)

Lab. cell = 40.8 %

230xAM1.5d, 1000 W/m²)

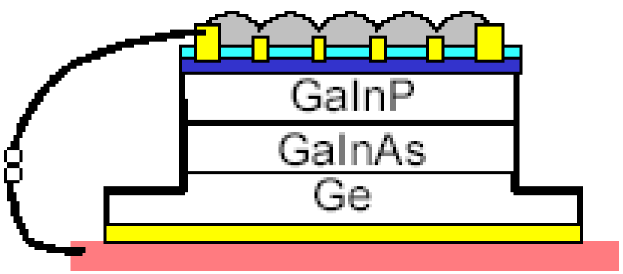



Source: E. Weber, FhG ISE

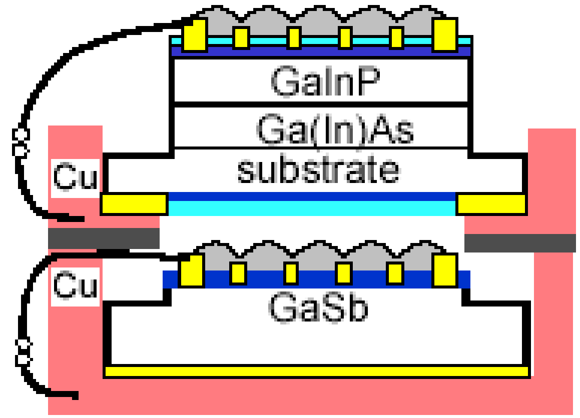
# Realization of Tandem and Triple Cells

## Monolithic cell




GaInP/GaAs/Ge:
32.4 % (C = 414 x, AM1.5d)

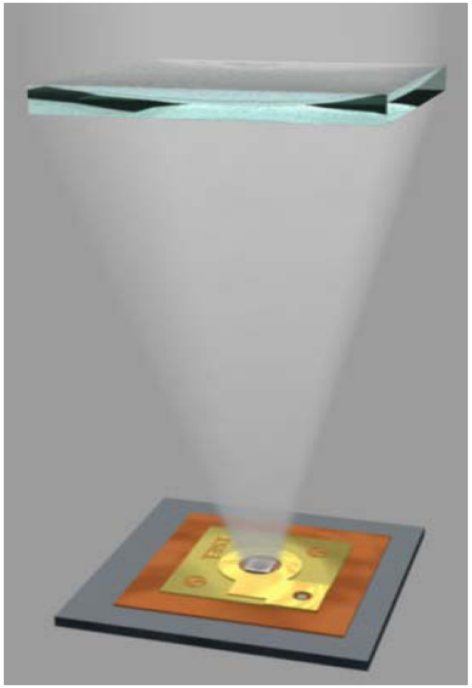
## Mechanically stacked cell




ISE: 33.4 % (C = 308)


Karlsruhe Institute of Technology

# Multi-junction solar cells for optical concentration, example



Source: J. Luther

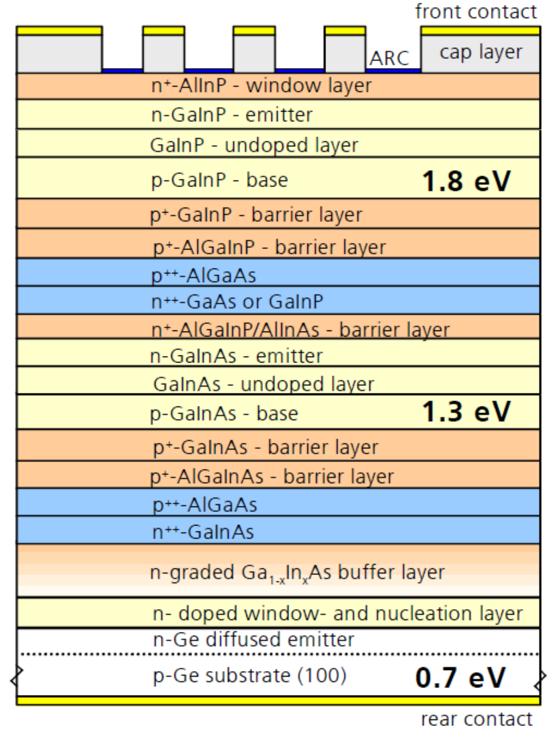
$Ga_{0.65}In_{0.35}P$

tunnel diode

$Ga_{0.83}In_{0.17}As$

tunnel diode

Ge




- high end and expensive (per area )
**epitaxial** growth of **crystalline** thin films

# Outline

6.7. Concentrator PV (CPV)

- 6.7.1 Introduction
- 6.7.2 Concentration effects
- 6.7.4 Multijunction solar cells
- 6.7.5 Epitaxy
- 6.7.6 State of the art and industry

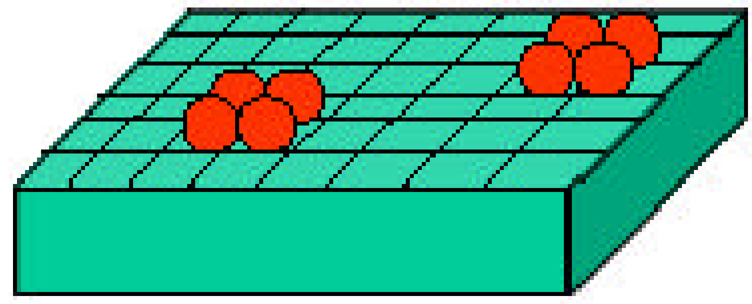
# Epitaxial Growth of Semiconductors

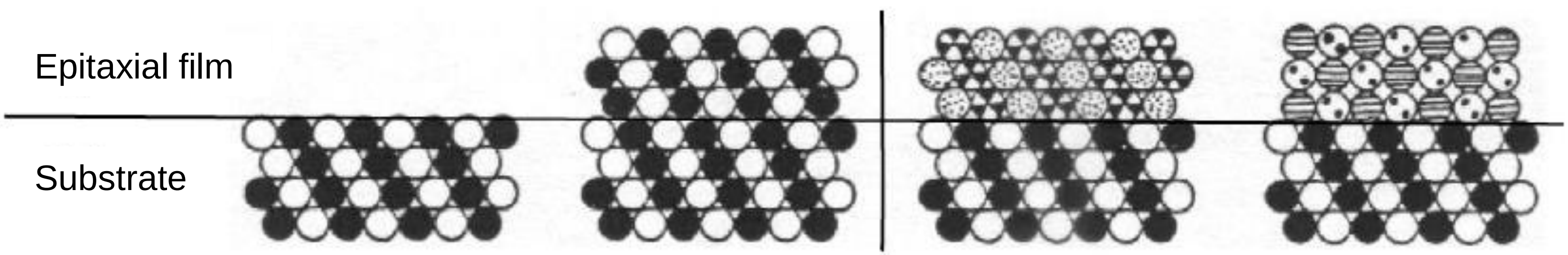
Growth is done as crystalline thin films on crystalline substrates

→ epitaxy growth (greek: to place onto in an ordered manner)

• epitaxy can be done on substrate with the same lattice constant

• growth of heterostructures is possible

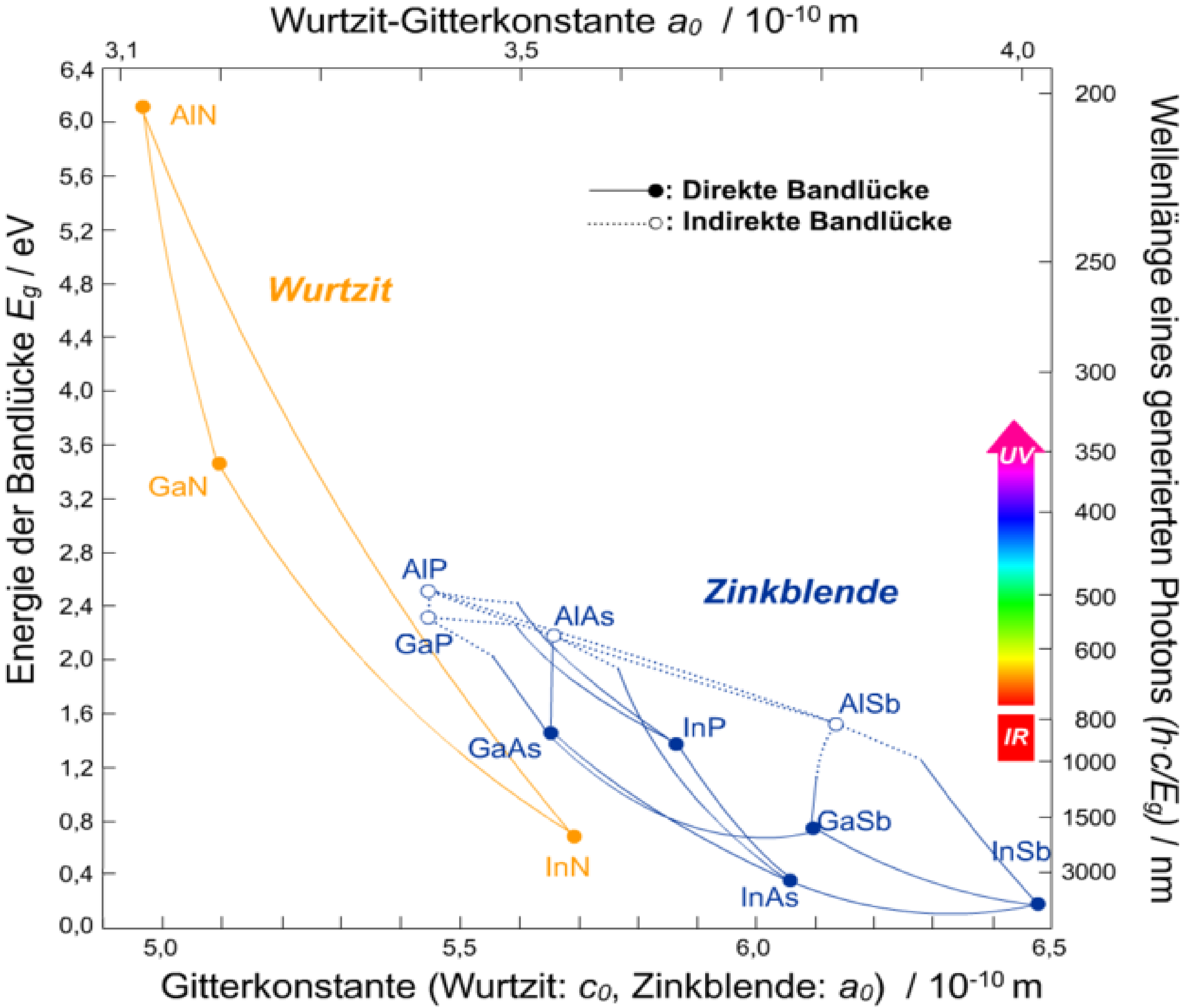





Homoepitaxy

Heterooepitaxy

# Bandgaps for different III-V-semiconductors



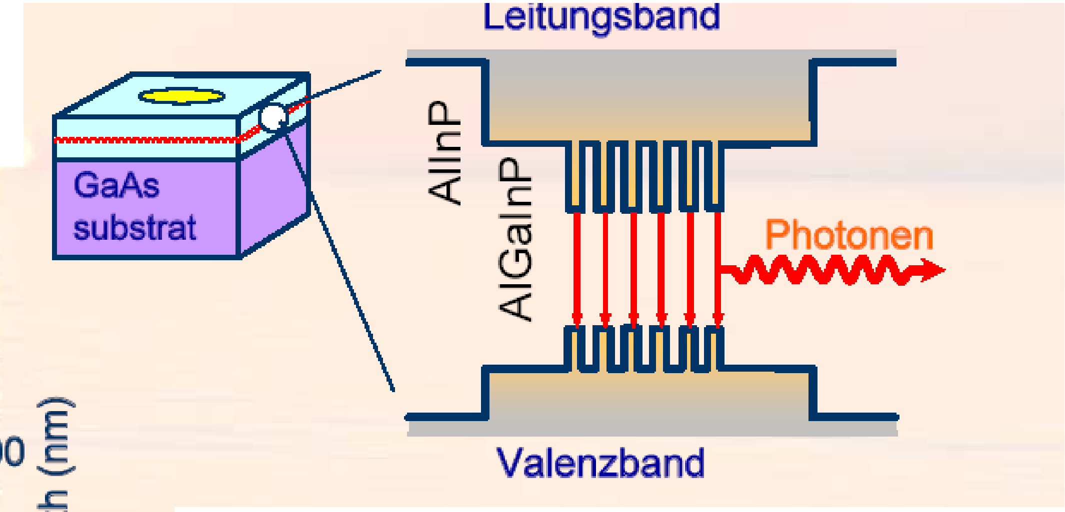

The bandgap can be adjusted by the choice of the material.

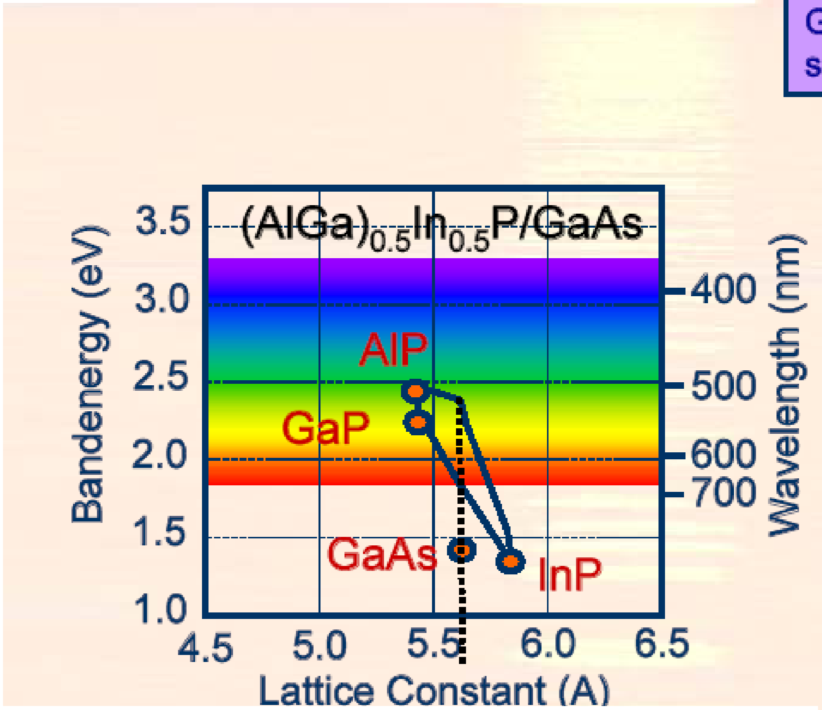
Source: www.wikipedia.de

# Epitaxial growth of heterostructures

**MOVPE: Metal Organic Vapor Phase Epitaxy**

The use of a quartenary material allows to tune the bandgap while the lattice constant remains the same.



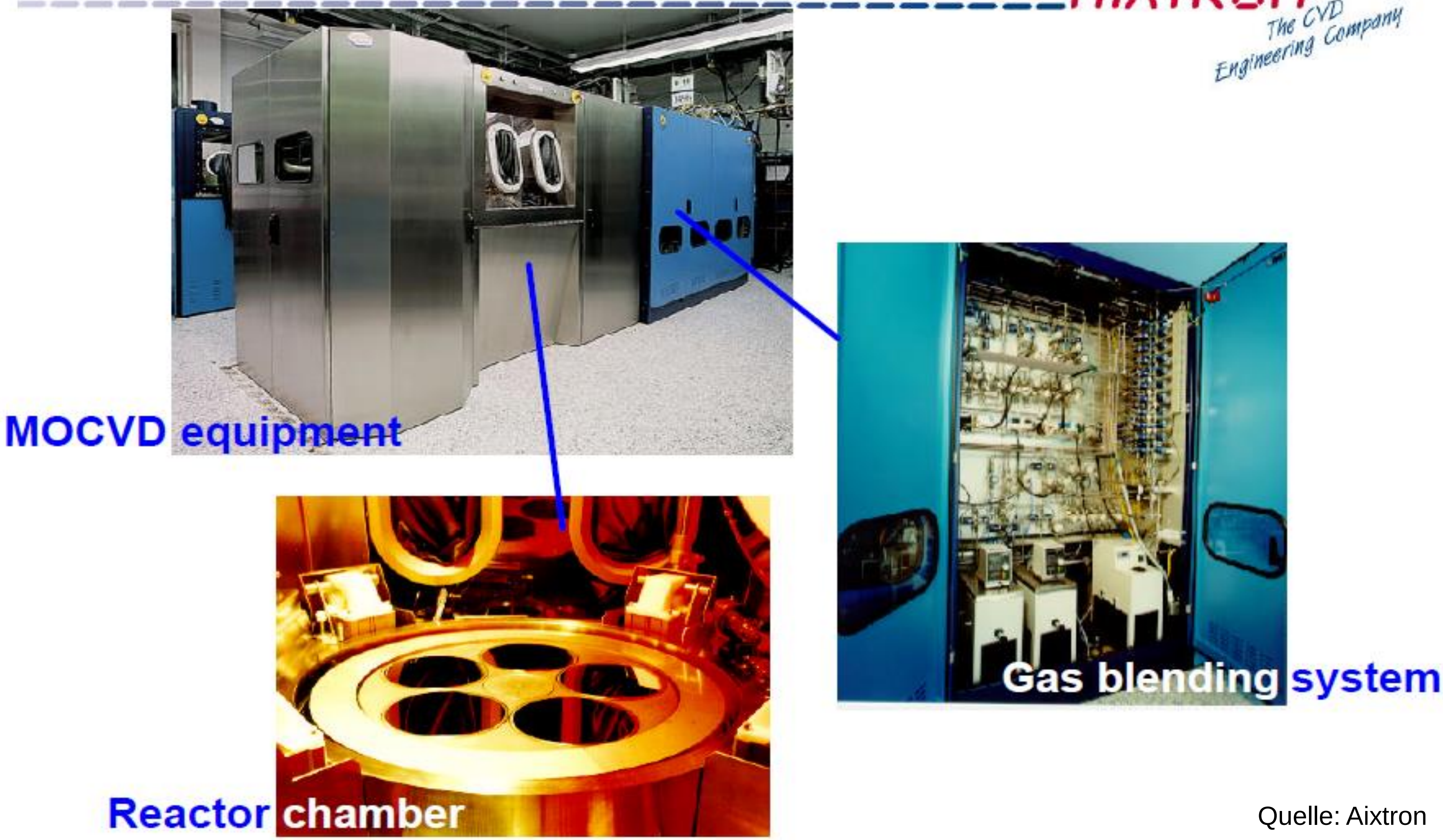

Scheme for AlGaInP-growth

Tailored bandgaps and tailored sequences of different bandgaps can be deposited.

Source: N. Stath, Osram OS

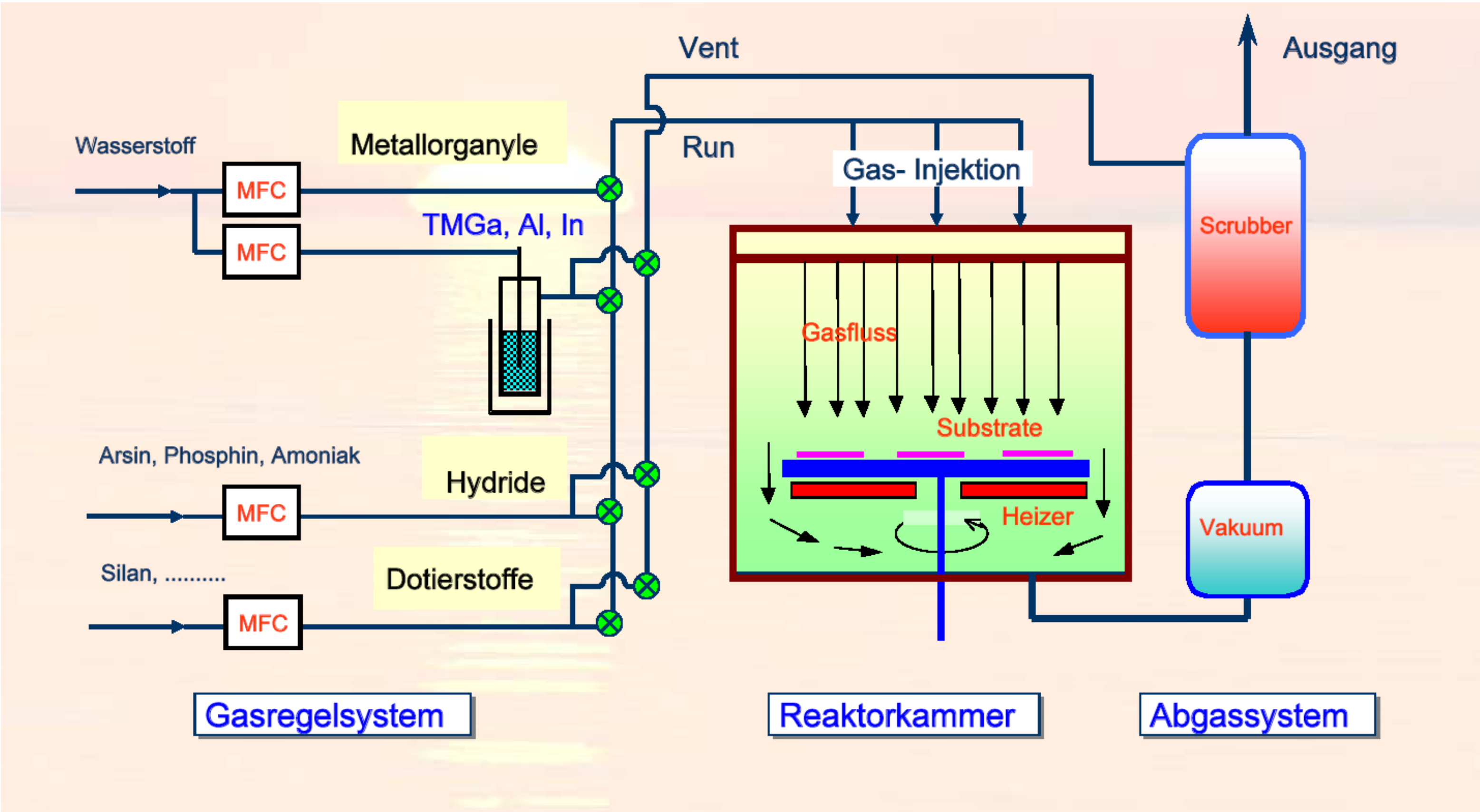
# Industrial epitaxy

AIXTRON The CVD Engineering Company




Quelle: Aixtron

# Industrial epitaxy




# MOCVD

(MOCVD;
Metal
Organic
Chemical
Vapor
Phase
Deposition)

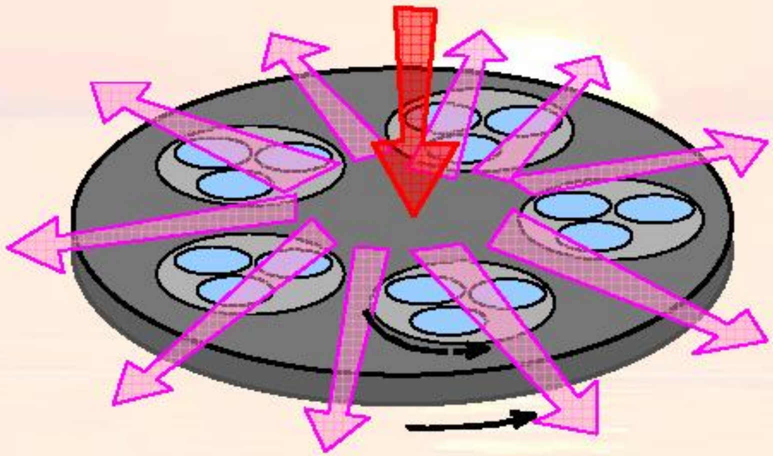
1. Precursor molecules are transported with a carrier gas to a heated substrate
2. thermal decomposition on the substrate
3. epitaxial growth

OSRAM

Source: N. Stath

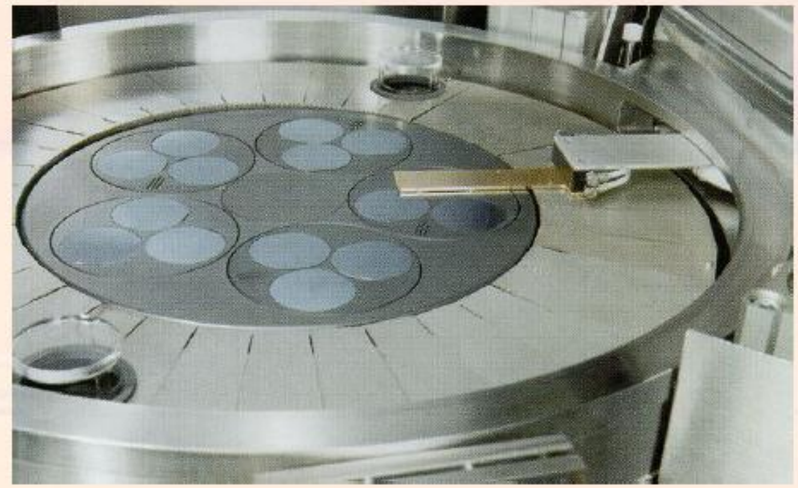
# Industrial epitaxy

Gasfluss-Schema mit $H_2$-Trägergas



Gas Foil Planetary Reactor (AIXTRON)

MOCVD-Produktionsanlage



MOCVD-Reaktor

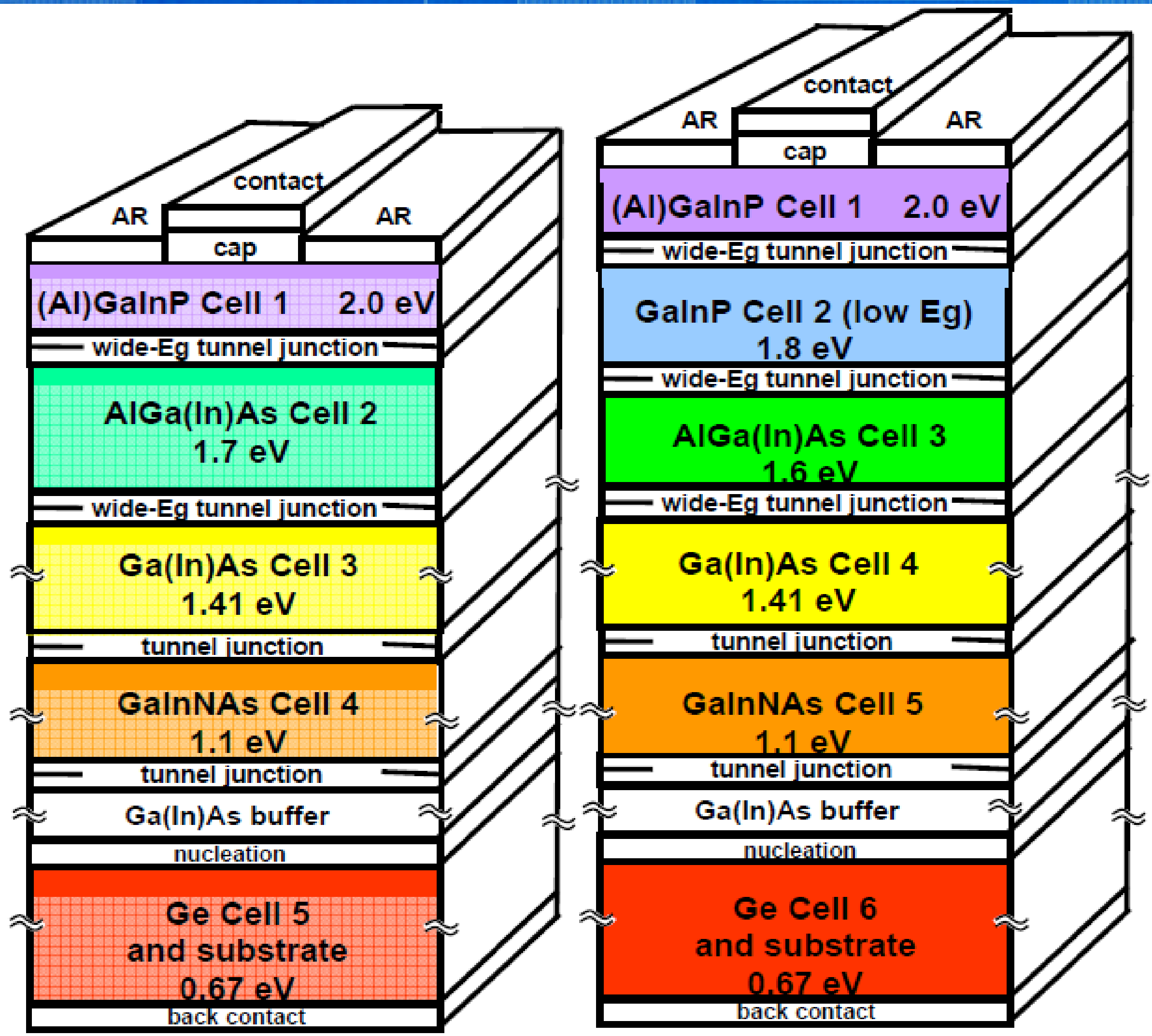
Abscheidereaktion bei 750°C - 800°C (Beispiel InGaAlP):

$$x\,Al(CH_3)_{3(v)} + y\,Ga(CH_3)_{3(v)} + z\,In(CH_3)_{3(v)} + PH_{3(v)} \rightarrow Al_xGa_yIn_zP_{(s)} + 3CH_{4(v)}$$

Source: N. Stath, Osram OS

Opto Semiconductors OSRAM

# 5- and 6-Junction Cells

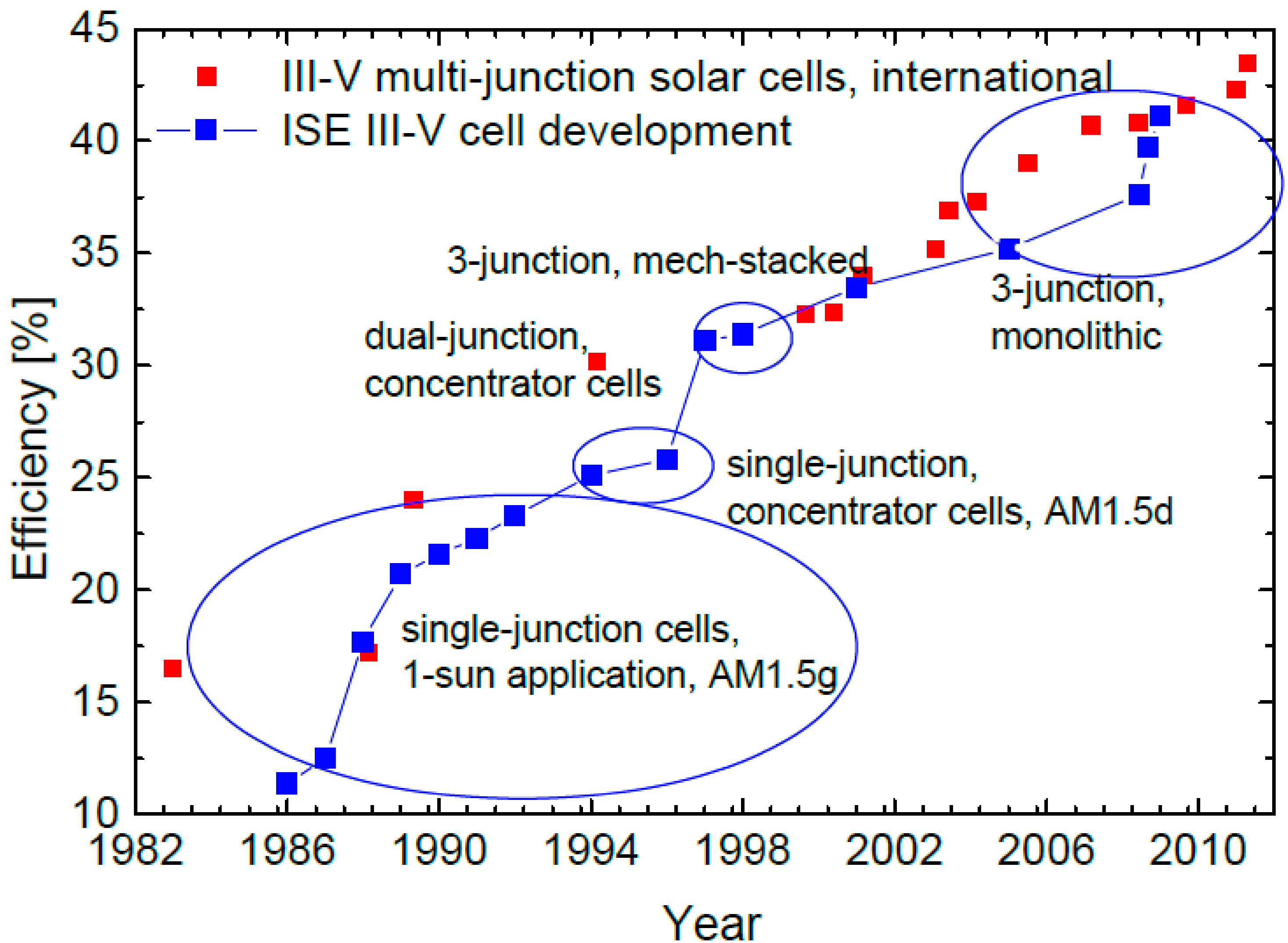



- Divides available current density above GaAs Eg among 3-4 subcells
- Allows low-current GaInNAs cell to be matched to other subcells
- Lower series resistance
- Thinner bases have potential for higher radiation resistance

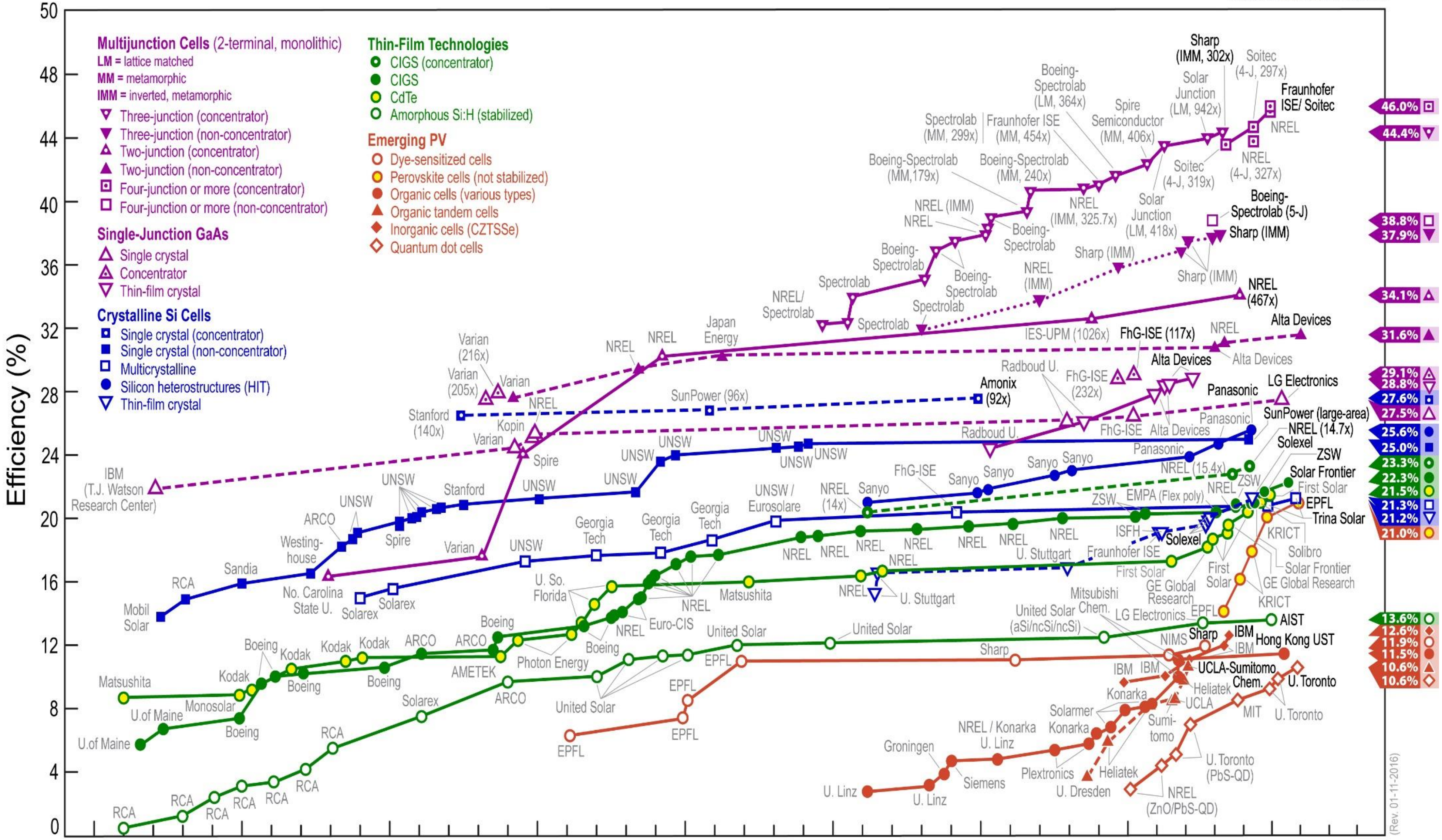
Ref.: U.S. Pat. No. 6,316,715, Spectrolab, Inc., filed 3/15/00, issued 11/13/01.

# Outline

# Evolution of  CPV efficiencies



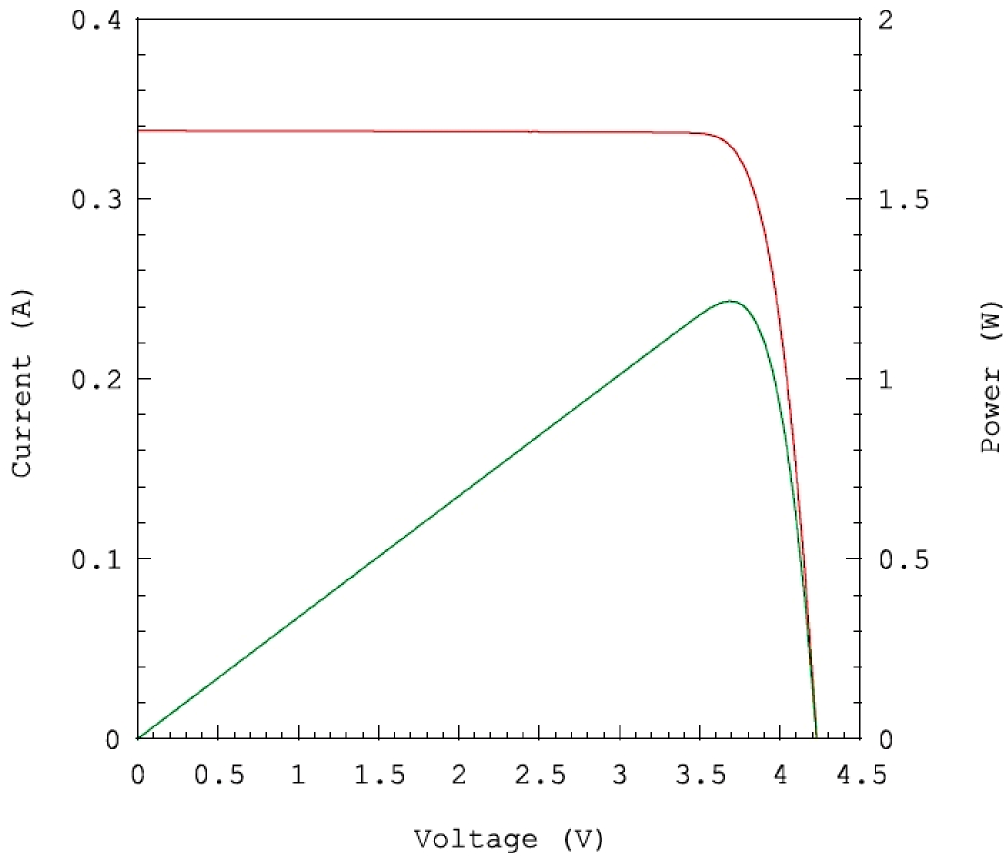
# Best Research-Cell Efficiencies



# 46% Efficiency Solar Cell (May 2015)

I-V CURVE

ASTM E927-10    0.0520cm² (designated area)  T-HIPSS




Date : 8 Oct 2014
Data No :
lot21-03-x19y04-01
Sample No :
lot21-03-x19y04
Repeat Times : 9

| | | |
|---|---|---|
| $I_{sc}$ | 337.9 | mA |
| $V_{oc}$ | 4.227 | V |
| $P_{max}$ | 1.215 | W |
| $I_{pmax}$ | 329.8 | mA |
| $V_{pmax}$ | 3.686 | V |
| F.F. | 85.1 | % |
| Eff(da) | 46.0 | % |
| DTemp. | 25.0 | ℃ |
| MTemp. | 24.6 | ℃ |
| DIrr. | 50.8 | W/cm2 |
| MIrr. | 50.9 | W/cm2 (1st) |
| | 50.8 | W/cm2 (2nd) |
| | 50.0 | W/cm2 (3rd) |
| | 50.9 | W/cm2 (4th) |

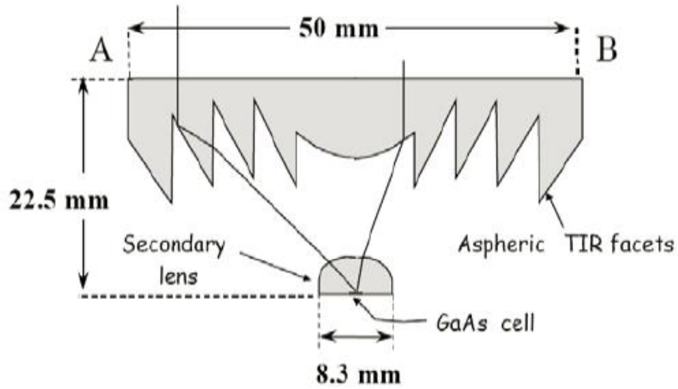
Scan Mode
Weighted average of
(Isc to Voc) and
(Voc to Isc)

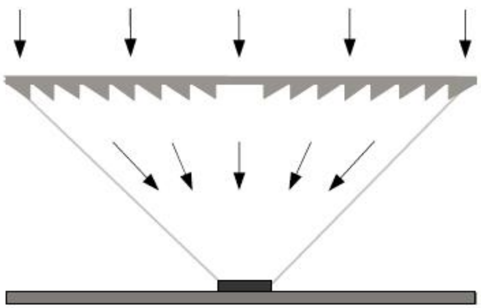
AIST

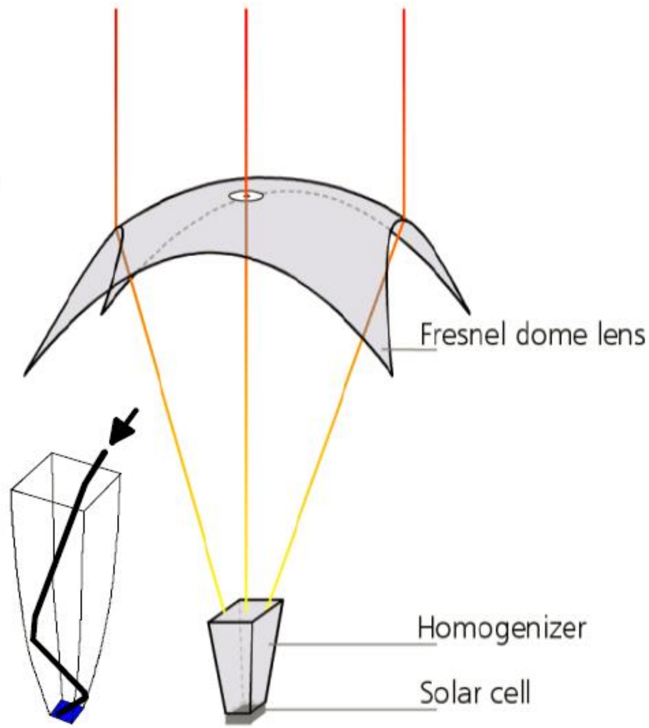


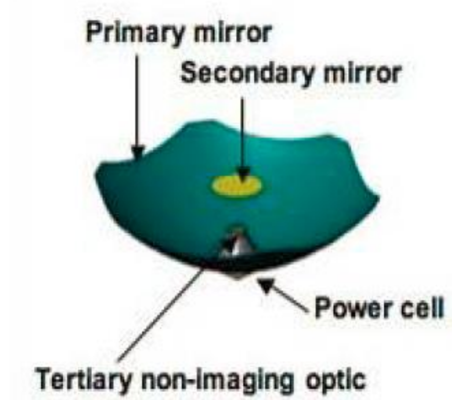
KIT Karlsruhe Institute of Technology

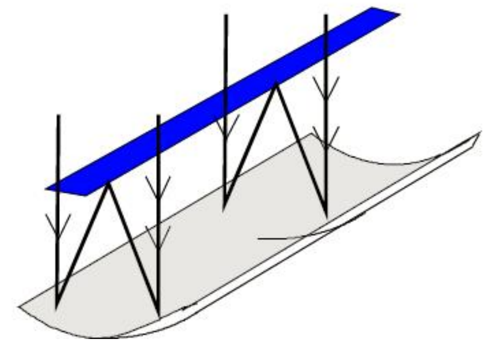
# Different optical concentrator designs





INVESTORS JOBS NEWS MEDIA CENTER Worldwide contacts Version française Search

Soitec

Home | About Soitec | Corporate responsibility | Markets | Technologies | Products & Services

Home | Solar energy

## Leading the solar energy revolution with Concentrator Photovoltaic (CPV) technology

Climate change and increasingly scarce fossil fuel supplies have sparked renewed interest in renewable energy sources. Solar energy is currently by far the most promising and sustainable renewable energy; rolling out photovoltaic systems that offer both performance and competitive energy prices is today a crucial energy issue. In 2010, the photovoltaic market saw unprecedented growth. An impressive 15 GW of new PV systems were installed worldwide, making PV solar energy the second leading type of electrical production capacity installed in 2010.

Concentrix™ technology has made Soitec the world's leading provider of CPV systems. Concentrix technology is the most competitive solution on the market, offers the best design for use in sunny regions, is environmentally-friendly, and delivers the highest efficiencies on the market.

Soitec CPV systems boast record sunlight-to-electricity conversion yields (currently 25%). These yields are expected to increase to 37% by 2015 – two to three times the efficiencies offered by standard photovoltaic systems.

### Markets

› Renewable energy

### Technologies

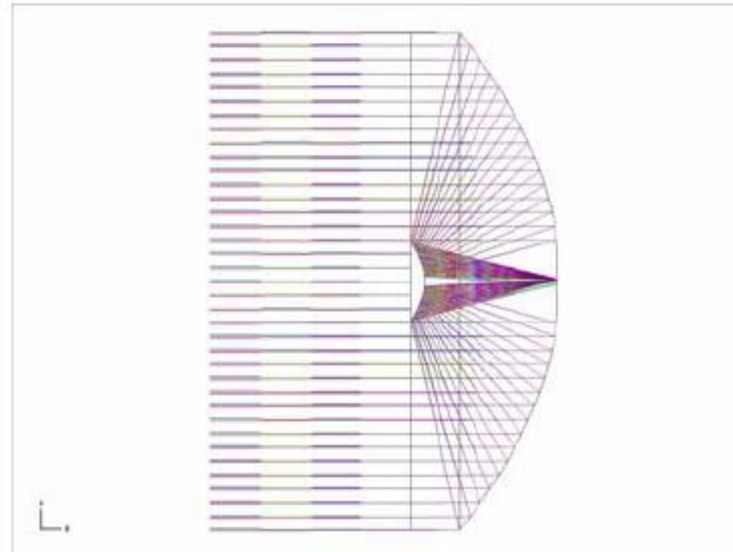
› Concentrix™

### Products & Services

› Solar CPV

# Optik Design @ SolFocus

*Figure 1: Generation 1 panel.*




Careers | Media | Contact Us | Customer Login | Sales Portal
English [change]
SolFocus
Innovation Inspired by Nature
Home | Technology | Solutions | Sustainability | Installations | Industry | News and Events | About Us
SolFocus CPV Systems
Delivering on the Promise of Clean, Low-Cost Solar Energy
SolFocus' leading CPV technology combines high-efficiency solar cells with advanced concentrating optics to provide high energy yield using just 1/1000th the amount of solar cell material used in traditional photovoltaic systems.
CPV Power Unit
CPV Panel
Dual-Axis Tracker
CPV System
SolFocus CPV panels are integrated with dual-axis trackers and precise tracker control systems, which are optimized for the SolFocus panels, to maintain high energy output throughout the day.
Featured Media
SolFocus: Factory to Field
Play Video

# The CPV market

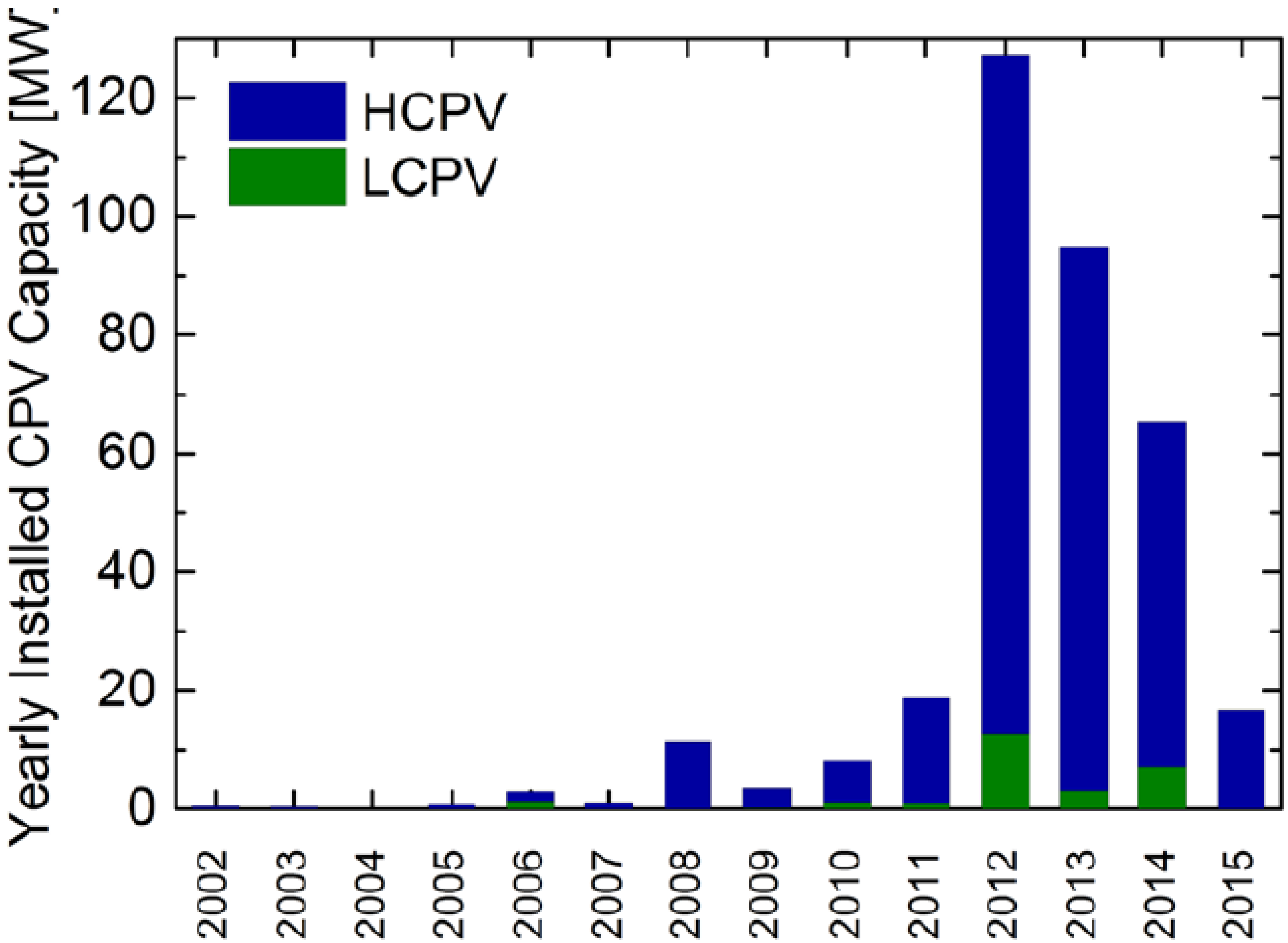



**Figure 2: CPV capacity installed each year with indication of the type (HCPV or LCPV), globally, as derived from public announcements, status January 2016.**

Source: Fraunhofer ISE

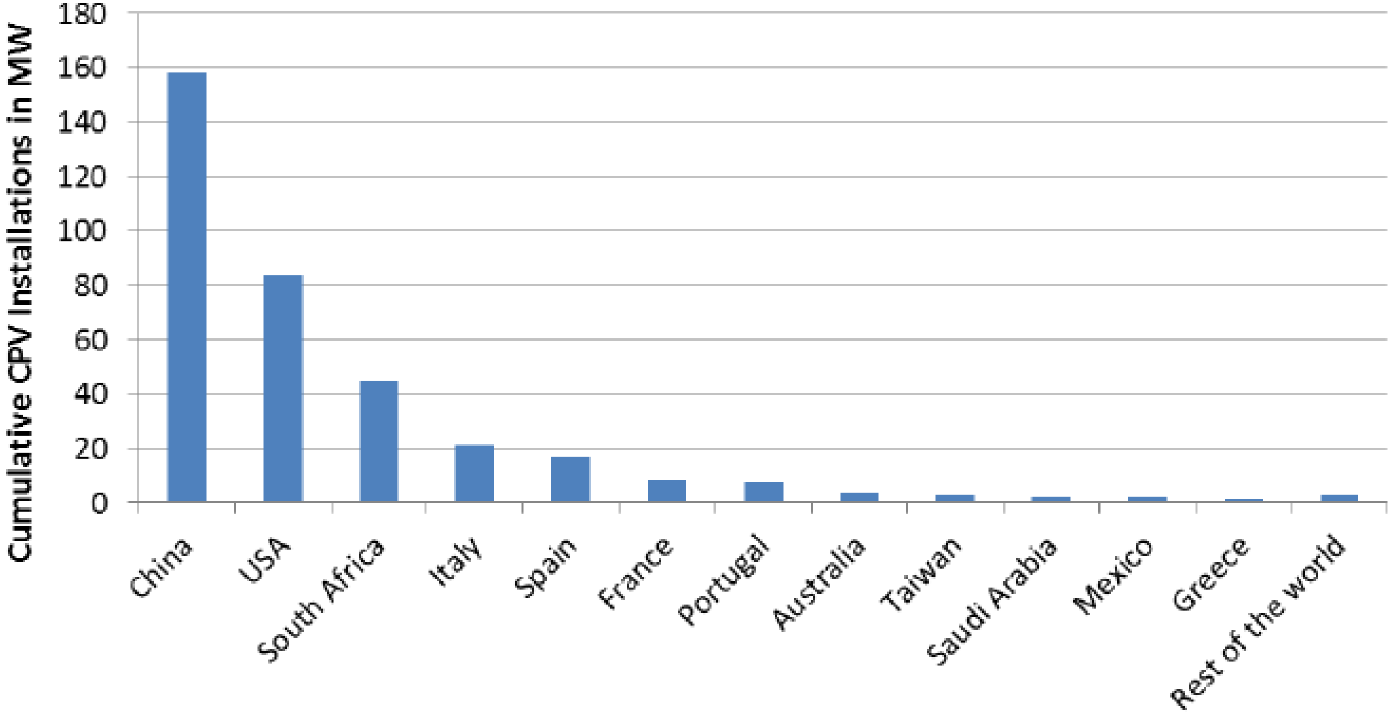



**Figure 4: Grid-connected CPV capacity by country through end of 2015. All countries with a total installation of 1 MWp or more are shown separately.**

Source: Fraunhofer ISE

## New world record for solar cell efficiency at 46%

**This success stems from French-German cooperation between Soitec, CEA-Leti and the Fraunhofer ISE and confirms competitive advantage of European photovoltaic industry**

*Bernin, France, and Freiburg, Germany, December 1st, 2014* – A new world record for the direct conversion of sunlight into electricity has been established. The record multi-junction solar cell converts 46 % of the solar light into electrical energy and was developed by Soitec and CEA-Leti, France, together with the Fraunhofer Institute for Solar Energy Systems ISE, Germany. Multi-junction cells are used in concentrator photovoltaic (CPV) systems to produce low-cost electricity in photovoltaic power plants, in regions with a large amount of direct solar radiation. The achievement of a new world record one year after the one previously announced in September, 2013 by these French and German partners shows the strong competitiveness of the European photovoltaic research and industry.

Home » Site map » Soitec To Give Up on Solar CPV

# Soitec To Give Up on Solar CPV

Though a promising technology, regular old solar PV beat concentrating PV (CPV) on cost and has led to another manufacturer deciding to call it quits.

January 20, 2015

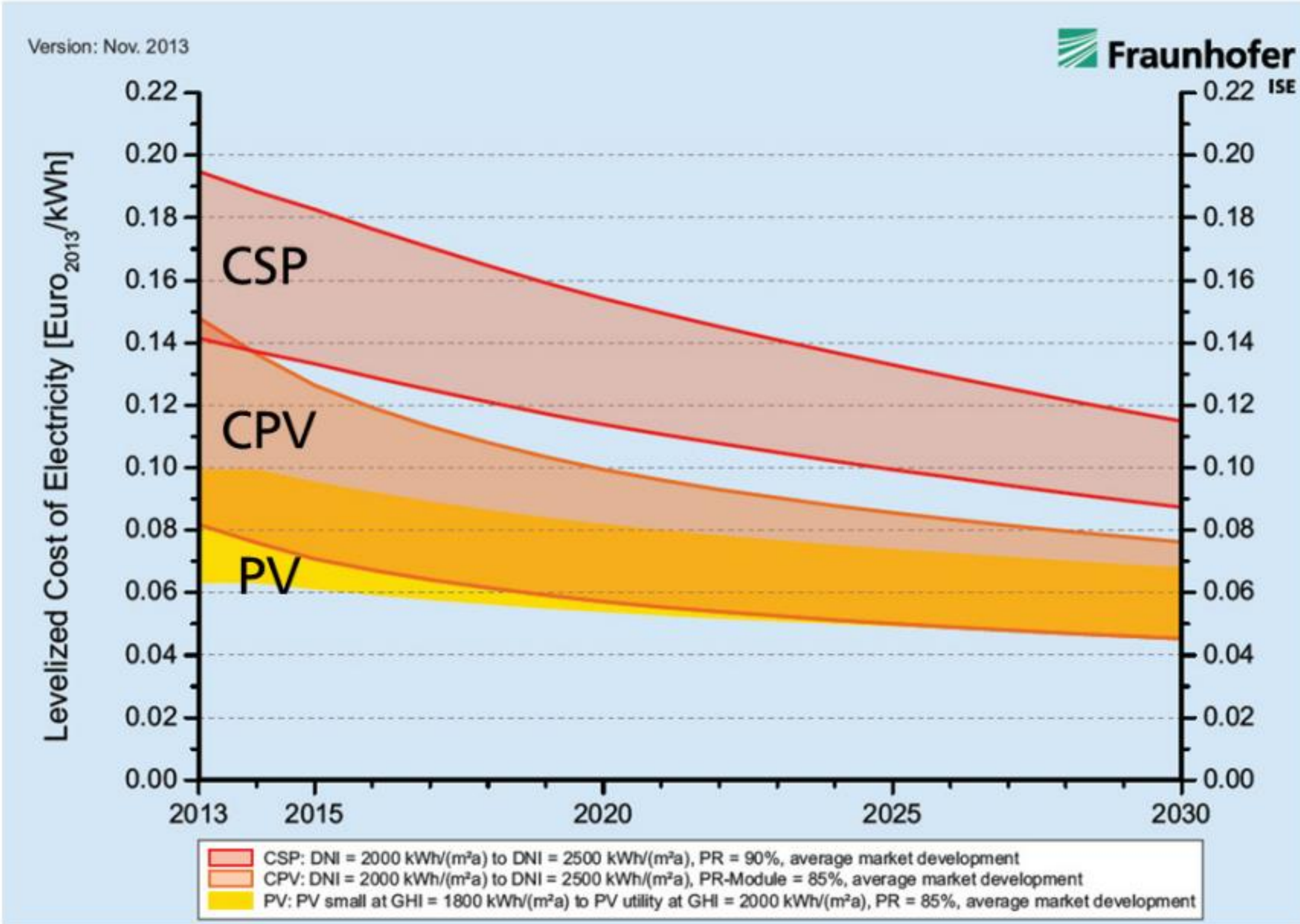



Figure 6: Development of the LCOE of PV, CSP and CPV plants at locations with high solar irradiation of 2000 kWh/(m²a) - 2500 kWh/(m²a). Source: [5].

Source: Fraunhofer ISE