


Reminders

- **Lab work: next week.**
 - Groups 1&2
 - Lab: 8.5.1
- **'Field' work: next week**
 - Groups 7&8
 - Rm:8.3.29
- **Test**
 - 18/12/2009 (2pm)
- **Advanced topics presentations**
 - To be defined (January)

Group	Students	LAB	FIELD
1	Joana Cereabela Clarisse Magalhães Lukas Fritz Luís Rodrigues	SR: 10/11/2009; 8am IV: 10/11/2009; 10am	17/11/2009; 8am
2	André Reis João Arsenio Ricardo Querido João Mário Pê	SR: 10/11/2009; 10am IV: 10/11/2009; 8am	17/11/2009; 10am
3	Ricardo Pratas Nuno Mateus Carolina Florindo Rita Fortes	SR: 17/11/2009; 8am IV: 17/11/2009; 10am	24/11/2009; 8am
4	Lúcia Silva Geoffrey Garcia Marta Santos Rúben Teixeira	SR: 17/11/2009; 10am IV: 17/11/2009; 8am	24/11/2009; 10am
5	Hugo Alves Carlos Carolina José Madeira Diana Lopes	SR: 24/11/2009; 8am IV: 24/11/2009; 10am	15/12/2009; 8am
6	Ana Bastos Carolina Fraga Rui Reis Vera Saravali	SR: 24/11/2009; 10am IV: 24/11/2009; 8am	15/12/2009; 10am
7*		SR: 15/12/2009; 8am IV: 15/12/2009; 10am	10/11/2009; 8am
8*	Ricardo E. Santos Carla Costa Fátela Rogério Proheno Tiago Correia Lara Silva	SR: 15/12/2009; 10am IV: 15/12/2009; 8am	10/11/2009; 10am

*This group is to be divided in 2 groups of 2+3. One of the subgroups will be in slot 7.



PV SYSTEMS

- BIPV – Building integrated PV
- CPV – Concentrated photovoltaics

Building integrated PV

- BIPV issues
 - Inclination
 - Orientation
 - Shading
 - Temperature
 - Design
- PV & architecture
- Categories of BIPV
- PV integrated in public spaces


Building integrated PV

- Optimal **inclination** for maximizing energy yield but aesthetically it may not make sense
- Optimal **orientation** usually south (north) but not always (e.g. in a region prone to early morning fog, optimal may be slightly to the west)

Building integrated PV

- Importance of **shading** – crucial during system & building design (micro-inverters make PV system more tolerant to shading mistakes)

Microinverters




Individual DC/AC converter at each module, also known as **AC module inverter** or **Plug-and-play PV module**

Advantages

- Plug and play concept allowing easy and cheap installation (does not require a certified engineer!)
- Modularity
- Lower BOS costs
- MPPT at module level: avoids mismatching losses, e.g. due to shade, dust, poor design, etc

Challenges

- Requires long term reliability (too many to replace!) in harsh conditions (mounted on the back of the module).
- Small inverters are less efficient than large ones
- Cost (requires mass production...)



S. Islam et al. Cost effective second generation AC-modules: Development and testing aspects, Energy 31 (2006) 1897–1920

Building integrated PV

- Importance of shading – crucial during system & building design (micro-inverters make PV system more tolerant to shading mistakes)
- Notice that **high surrounding buildings** may also alter (i.e. usually block!) diffusive light

Building integrated PV

- Importance of **temperature**: (ventilated) air gap behind module to keep 'low' module temperature (extra: insulating function!)
- **Design!**
 - 'High-tech' or 'Green' look
 - Replacement for other facade materials (e.g. office building)

**ARCHITECTURAL INTEGRATION:
CRITERIA FOR GOOD PV ARCHITECTURE**

Task 7 of the IEA PVPS programme

- **Natural** part of the system (e.g. to form a logical part of the building)
- Architecturally **pleasing**
- Good **composition** of colours and materials
- Fits the **gridula** (e.g. in harmony with the rest of the building)
- Matches the **context** of the building
- Well **engineered**
- **Innovative** design

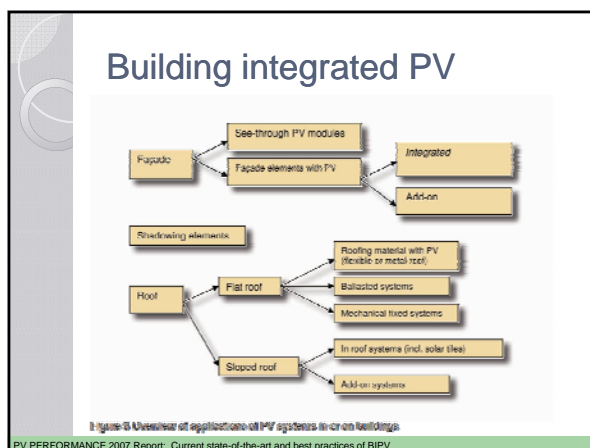
H. Kaan, T. Reijenga, *Photovoltaics in an Architectural Context*, Prog. Photovolt: Res. Appl. 2004; 12:395–408

HOW CAN PV BE INCORPORATED INTO THE BUILDING DESIGN?



- **Invisible**
- **Added** to the design
- **Adds** to the architectural image
- **Determines** the architectural image
- **Leads** to new architecture concepts

Increasing architectural value

H. Kaan, T. Reijenga, *Photovoltaics in an Architectural Context*, Prog. Photovolt: Res. Appl. 2004; 12:395–408

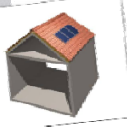



Building integrated PV

Flat roof	
	
Ballasted system	Mechanical fixed system

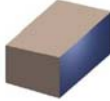
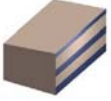
PV PERFORMANCE 2007 Report: Current state-of-the-art and best practices of BIPV

Building integrated PV

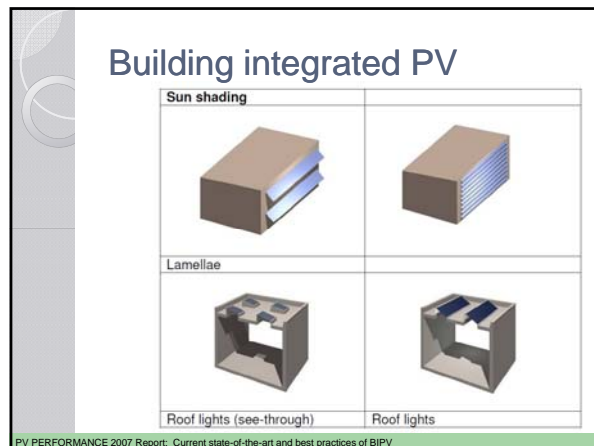
Sloped roof	
	
Add-on system	Integrated

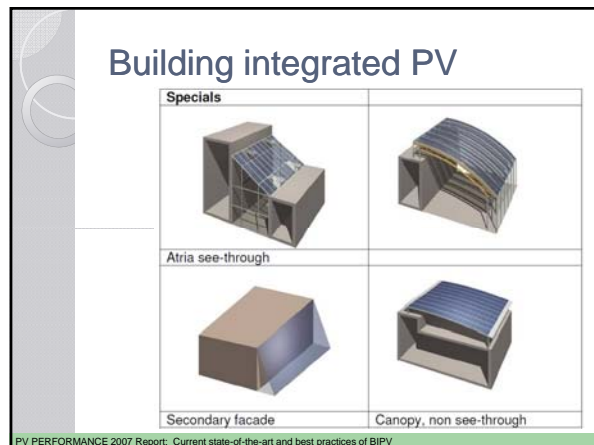
PV PERFORMANCE 2007 Report: Current state-of-the-art and best practices of BIPV

Building integrated PV

Façade systems	
	
Curtain wall, integrated	Parapet, integrated

PV PERFORMANCE 2007 Report: Current state-of-the-art and best practices of BIPV





BIPV in public spaces

- Increase locally produced renewable **electricity**
- Bring PV closer to the **people**
- Promote **sustainability** (usually more visible than when in/on buildings)
- Examples:
 - Urban street equipment
 - Shelters, barriers, shading structures
 - Urban art

BIPV in public spaces

Main design issues

- Solar **resource** (shadings more likely)
- Visual **appearance** (key issue)
- **Vandalism** and theft
- Easy **maintenance**
- **Cost**

BIPV

- More info on BIPV:
<http://www.pvdatabase.org/>
<http://www.pvupscale.org/>
<http://iea-pvps-task10.org/>

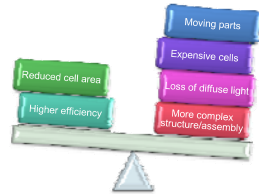
CPV – CONCENTRATION PV

- Concentration concept
- Solar cells under concentration
- Categories of concentration
 - Including luminescent concentrators
- Solar cells for concentration
 - Silicon
 - Multijunction
- What is the best CPV technology?

CPV – CONCENTRATION PV

Concentration concept

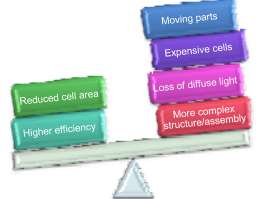
- Replace expensive solar cell by cheaper materials, e.g. mirrors and/or lenses
- 'Allows' for the use of more efficient (i.e. expensive) solar cells



CPV – CONCENTRATION PV

Concentration concept

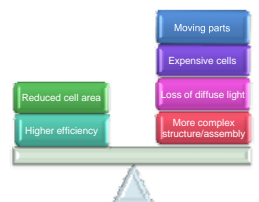
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CPV – CONCENTRATION PV

Concentration concept

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CPV – CONCENTRATION PV

Solar cells under concentration X

- Increased irradiance

$$G(X) = X G(1)$$

- Increased current

$$I_{sc}(X) = X I_{sc}(1)$$

- Increased voltage

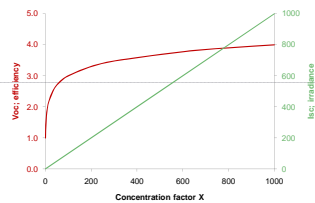
$$V_{oc}(X) = \frac{KT}{q} \ln \left(\frac{I_{sc}(X)}{I_0} + 1 \right) \approx \frac{KT}{q} \ln \left(X \frac{I_{sc}}{I_0} \right) \quad V_{oc}(X) = V_{oc}(1) + \frac{KT}{q} \ln(X)$$

- Increased efficiency:

$$\eta(X) = \frac{V_{oc}(X) I_{sc}(X) KMP}{G(X)} \quad \eta(X) = \eta(1) \left(1 + \frac{KT \ln(X)}{q V_{oc}(1)} \right)$$

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Solar cells under concentration X

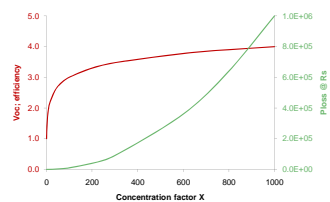


- Increased series resistance loss

$$R_{loss} = I^2 R_s = X^2 I_{sc}(1)^2 R_s$$

CPV – CONCENTRATION PV

Solar cells under concentration X



- Optimum concentration for a given cell

$$X = \frac{KT/q}{V_{oc}(1) R_s}$$

CPV – CONCENTRATION PV

'Possible' classification scheme for CPV

Concentration factor X

Small
X = 2 to 100

Middle
X = 100 to 300

Large
X = 300 to >1000

CPV – CONCENTRATION PV

Another 'possible' classification scheme for CPV

Tracking

1-axis
(X<100)

2-axis
(X>100)

Other
(static or 1-axis+secondary)

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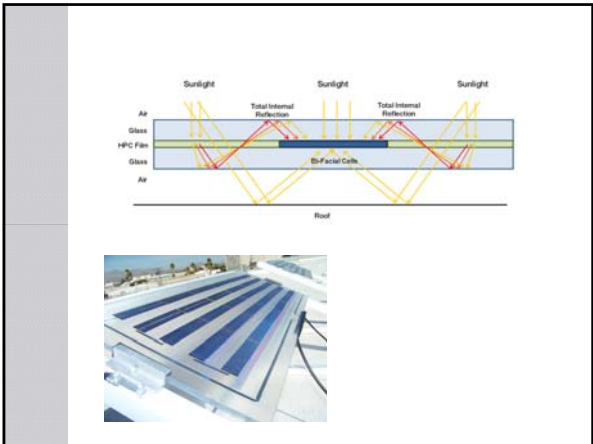
Another 'possible' classification scheme for CPV

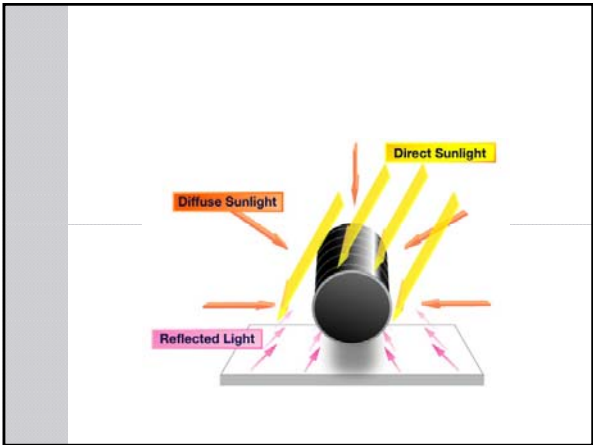
Type of concentration

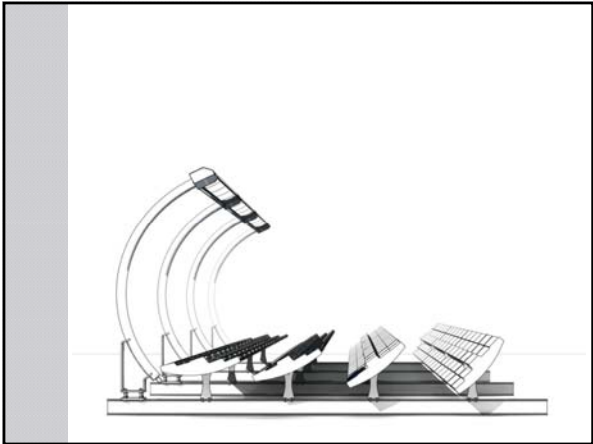
Reflective
(mirror)

Refractive (lenses)
(or secondary concentrator)

Other
e.g. Fluorescence collectors



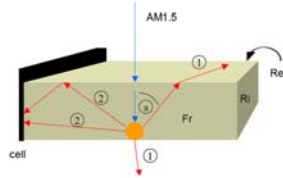
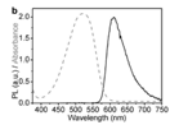




CPV – CONCENTRATION PV

Luminescent concentrator

- Old idea A.Goetzberger et al, Appl. Phys. 14, 123 (1977)
- Recently back to fashion M.Currie, Science 321, 226 (2008)
- (Potentially) low cost
- No tracking required
- Low efficiencies (<7%)
- Short lifetime (days)



L.H. Sloof et al, Luminescent concentrator: a bright idea for spectrum conversion?, 20th European PV Conference, Barcelona, 2005

CPV – CONCENTRATION PV

Luminescent concentrator

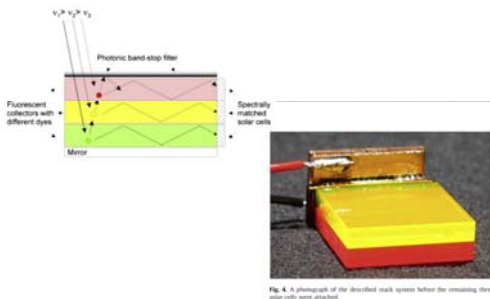


Fig. 4. A photograph of the described stack system before the connecting three solar cells were attached.

J.C. Goldschmidt et al, Increasing the efficiency of fluorescent concentrator systems, Solar Energy Materials & Solar Cells 93 (2009) 176–182

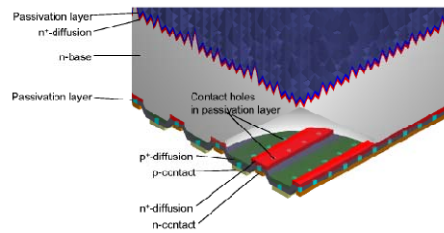
CPV – CONCENTRATION PV

High efficiency silicon solar cells

- High **quality** silicon: lifetime \gg thickness
- Strong **doping** below contacts
 - To reduce contact resistance
 - To reduce recombination
- High quality **surface** passivation, textured surface & antireflective film
- Back **contact** or emitter wrap through
 - Increased thickness to reduce series resistance
 - Reduced thickness to increase area

CPV – CONCENTRATION PV

High efficiency silicon solar cells



CPV – CONCENTRATION PV

High efficiency multijunction solar cells

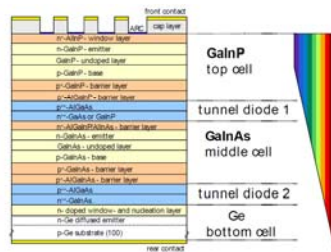
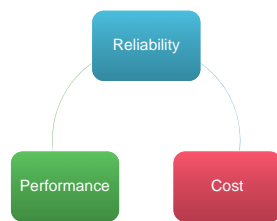


Figure 4-2: Schematic layer system of a GaInP/GaInAs/Ge triple solar cell on Ge substrate.

A. Bett *et al*, Concentration PV, in The Strategic Research Agenda (SRA), EU Photovoltaic Technology Platform, 2006

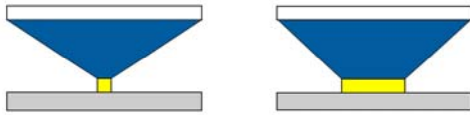
CPV – CONCENTRATION PV

So many options, what's the best CPV?



CPV – CONCENTRATION PV

So many options, what's the best CPV?



Choosing the 'right' concentration factor X

- Cost of rigid structure
- Cost of solar cell
- Efficiency of solar cell
- Alignment issues (wind, thermal expansion, assembly tolerance)

CPV – CONCENTRATION PV

So many options, what's the best CPV?



Large cells and optics

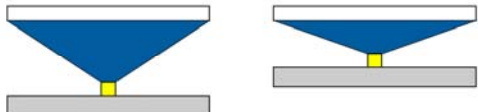
- ✓ Reduced part count
- ✓ Rigid structure
- ✓ Can use active cooling
- ✓ Modularity can be advantage

Small cells and optics

- ✓ Reduced material cost
- ✓ Aesthetic appeal
- ✓ Heat is distributed
- ✓ Smaller current

CPV – CONCENTRATION PV

So many options, what's the best CPV?



Higher f number

- ✓ Easier assembly (higher tolerance to misalignments)

Lower f number

- ✓ Reduced thickness
- ✓ Innovative and more appealing design

CPV – CONCENTRATION PV

So many options, what's the best CPV?

The jury is still out...

Time will tell which one is best, if any.

CPV – CONCENTRATION PV

Research institutes

- ENEA (PhoCUS project)
- FhISE (FLATCON; Concentrix spinoff)
- IES-UPM (spinoffs: Isofoton, Inspira)
- ISFOC (demonstration site)

Companies

- **WS Energia**
- **Magpower**
- Amonix
- Entech
- Emcore
- Solfocus

**Who's who
in CPV**

CPV – CONCENTRATION PV

Further reading on CPV

- A. Luque *et al*, *Concentrator photovoltaics*, Springer 2007
- A. Bett *et al*, *Concentration photovoltaics*, in The Strategic Research Agenda (SRA) report, EU Photovoltaic Technology Platform, 2006
- R. Swanson, *The promise of concentrators*, Prog. Photovolt. Res. Appl. 8, 93-111 (2000)
- S. Kurtz, *Opportunities and challenges for development of a mature concentrating PV power Industry*, Technical Report NREL/TP-520-43208 (2009)
