High Concentrating Photovoltaics

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ECE 4833

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Components of HCPV

- Concentrating Optics magnify the incident light on the solar cell, increasing the light intensity to hundreds of suns.
- High efficiency solar cells are often used in HCPV because much less semiconductor is needed.
- Tracking systems are necessary because the acceptance angle of the optics is very small in order to correctly concentrate the light.

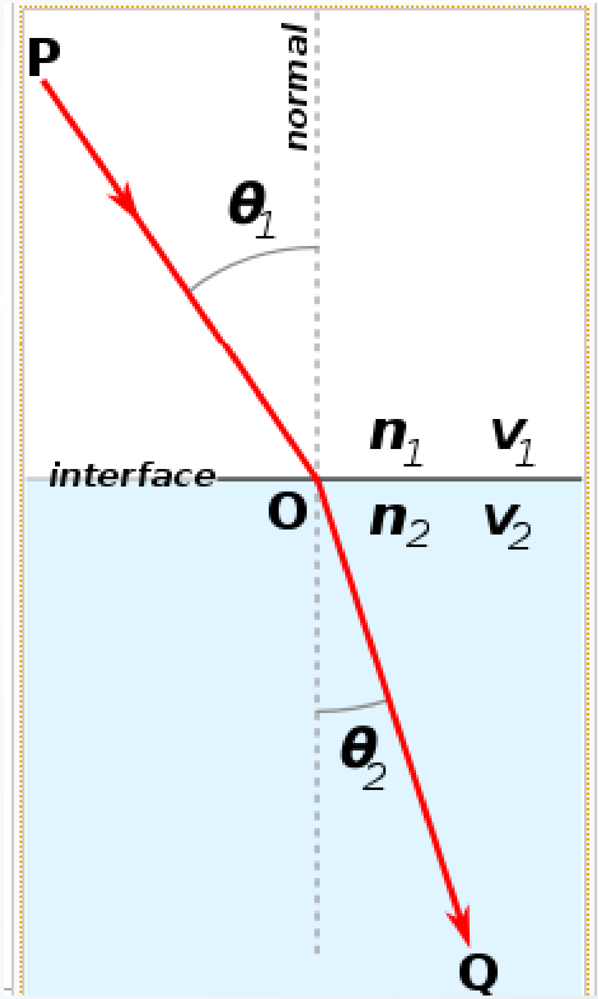
Concentrating Optics

- Spherical Lenses
- Fresnel Lenses
- Cassegrain Optics
- Parabolic Mirrors
- Secondary Optics
- Light-guide Solar Optic

Snell's Law

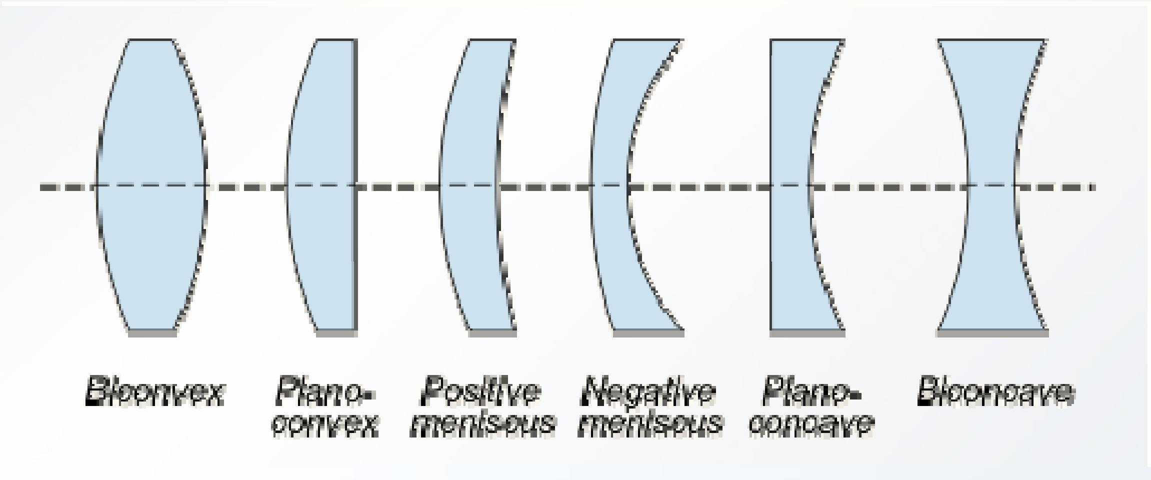
- The behavior of light traveling through a lens is governed by Snell's Law.

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2} = \frac{n_2}{n_1}$$



Spherical Lenses

- The surface of a spherical lens can be convex, concave, or planar.
- The radius of each surface determines the focal length of the lens and whether the incident light converges or diverges.



Lensmaker's Equation

f = focal length of the lens

n = refractive index of the lens

R1 = radius of curvature (surface closest to light source)

R2 = radius of curvature (surface furthest from light source)

d = lens thickness along the axis

$$\frac{1}{f} = (n-1)\left[\frac{1}{R_1} - \frac{1}{R_2} + \frac{(n-1)d}{nR_1R_2}\right]$$

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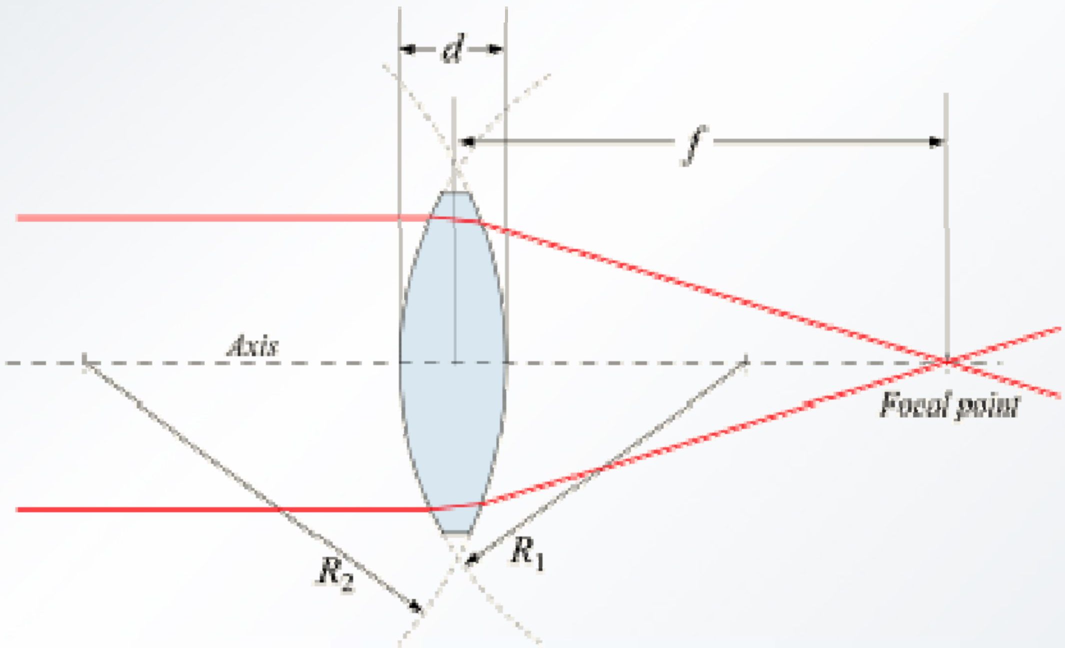
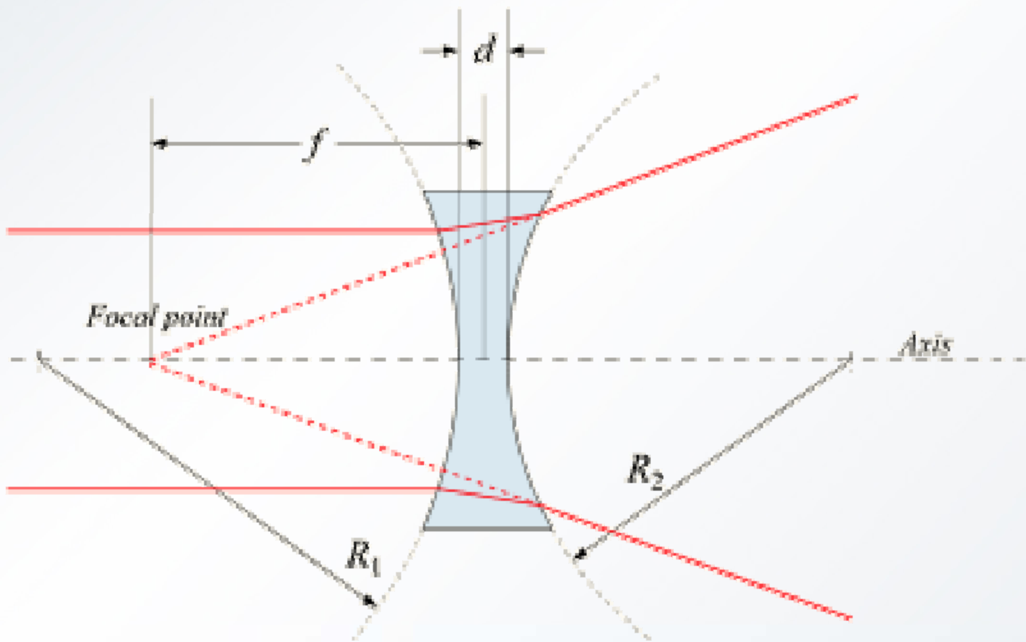


Positive (converging) lens

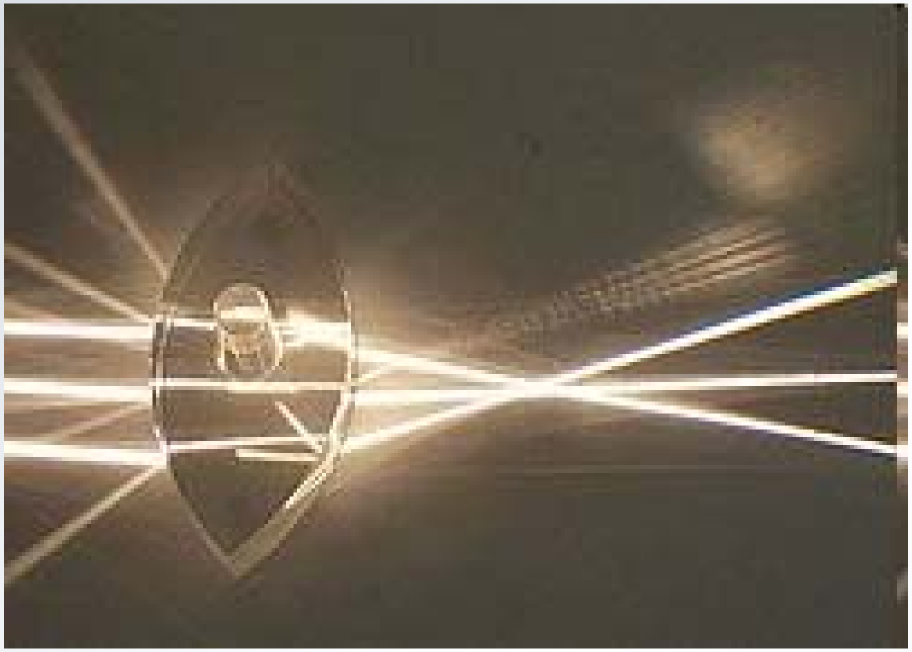
Lensmaker's Equation

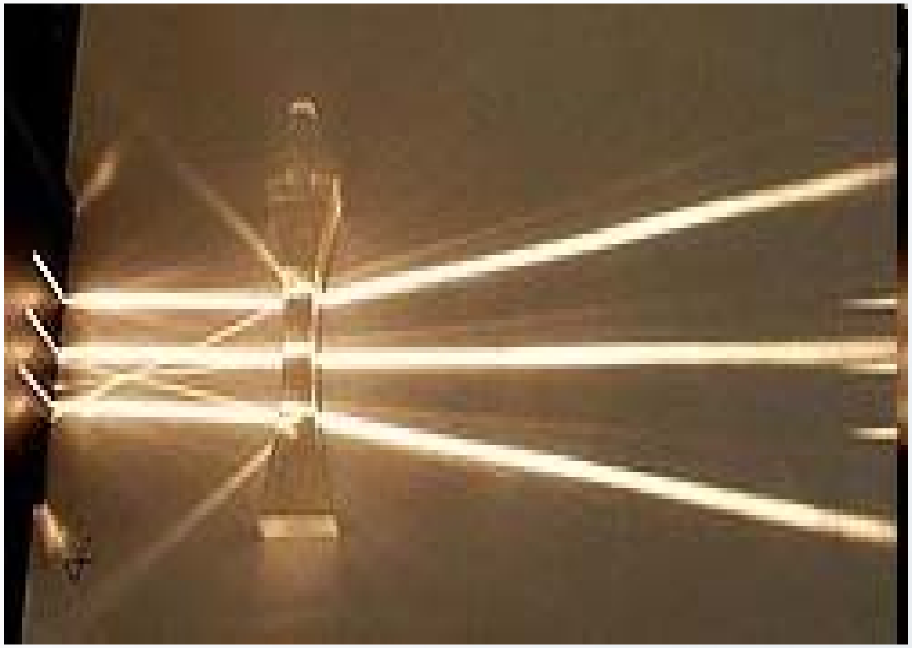
$$\frac{1}{f} = (n-1)\left[\frac{1}{R_1} - \frac{1}{R_2} + \frac{(n-1)d}{nR_1R_2}\right]$$



Negative (diverging) lens

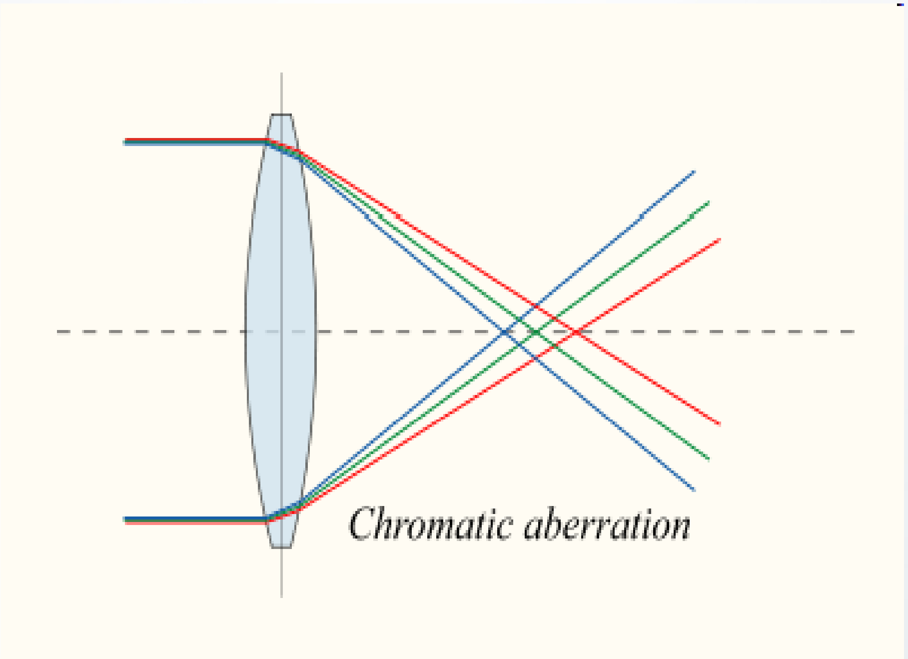
Convergence and Divergence





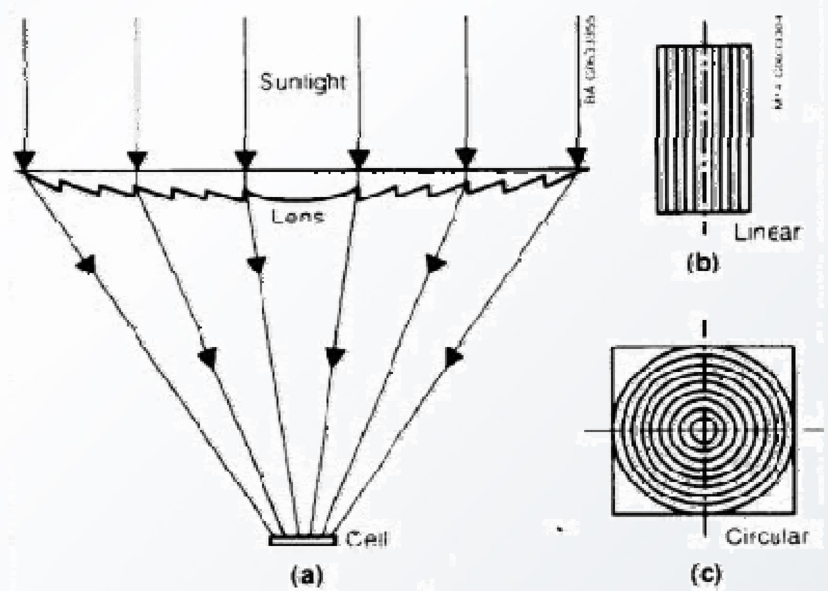
Dispersion

- The refractive index of a material is actually slightly dependent on wavelength.
- Because of this, different wavelengths of light have slightly different focal lengths.
- Dispersion can be corrected by using a secondary optic with dispersive properties inverse to the first lens.



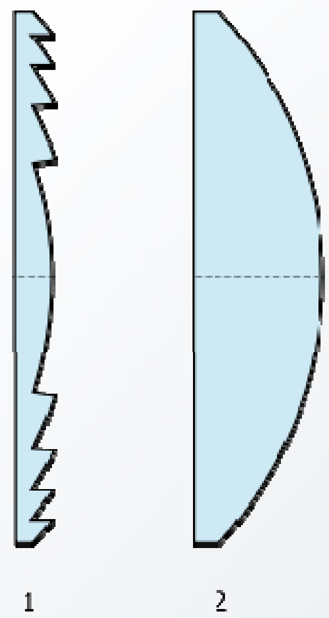
Fresnel Lens

- Spherical lenses are too large and too heavy to use as large aperture optics in HCPV. One solution to that is the Fresnel lens.
- Fresnel lenses are made of radial sections called "Fresnel Zones".
- Each section of the lens has the same curvature.



Advantages of the Fresnel Lens

- Fresnel lenses(1) are much thinner than a plano-convex lens(2).
- The focal length of a Fresnel lens is shorter than a spherical lens of the same aperture size.
- Fresnel lenses use less material, and therefore weigh less than spherical lenses.



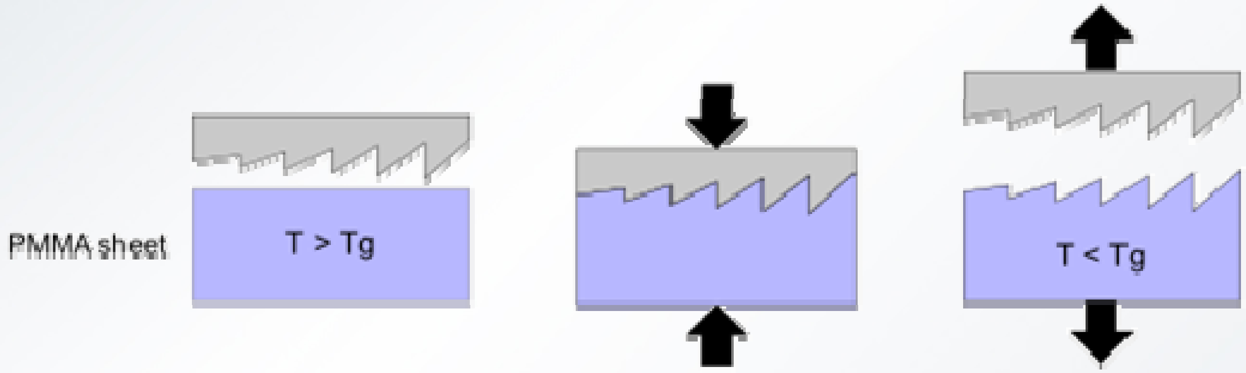
Lens Material

- Two common materials for Fresnel lenses are Polymethyl methacrylate (PMMA) and Silicone on glass.
- PMMA has a refractive index of 1.49
- Silicone has a refractive index between 1.41 and 1.42

http://www.concentratoroptics.com/

Fabrication of a Fresnel Lens (PMMA)

- PMMA is heated above the glass transition temperature and the mold is placed in the material.
- The material is then cooled and mold removed.



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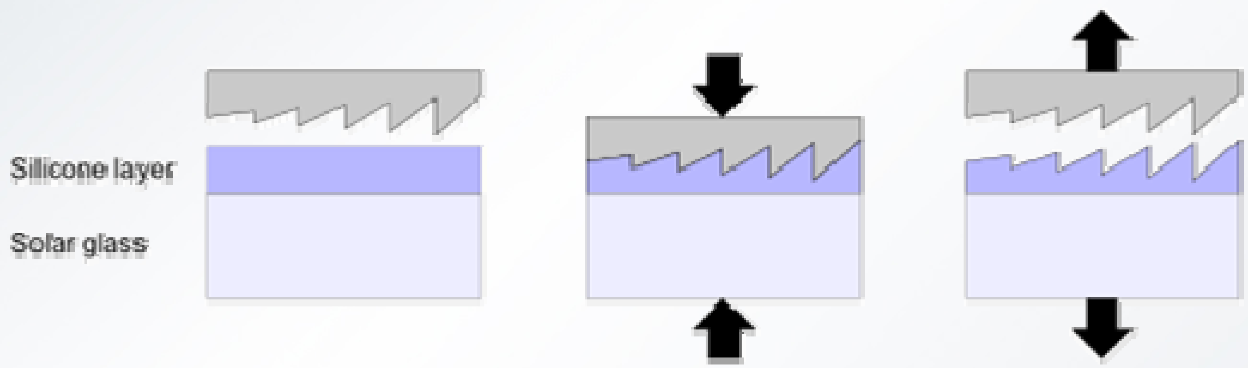
Fabrication of a Fresnel Lens (SoG)

- Liquid silicone is applied to solar glass.
- The silicone is polymerized in the mold at low pressure.
- The mold is then removed.



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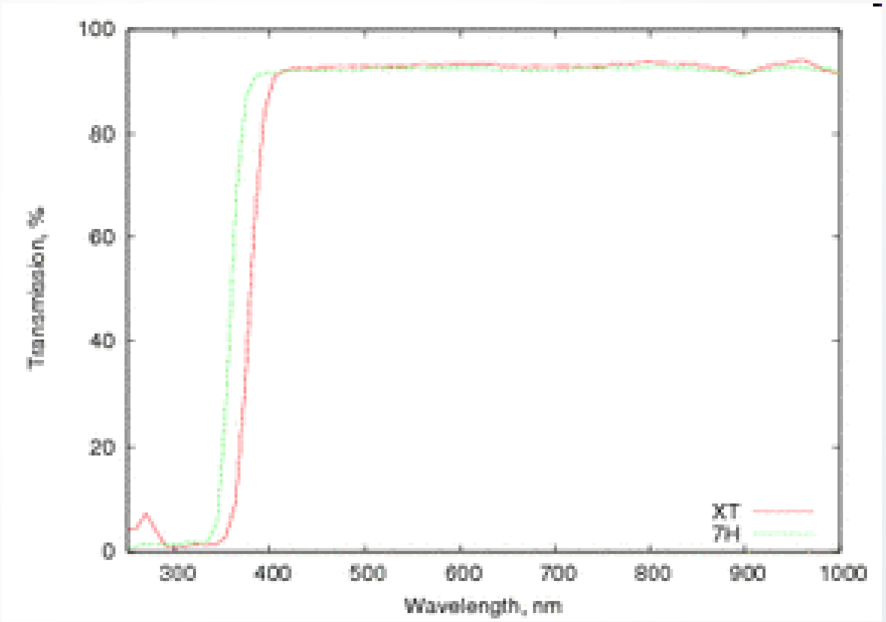
Transparency of PMMA

- Concentrator Optics uses two types of PMMA for their Fresnel lenses: standard PMMA and UV-enhanced PMMA.
- Standard PMMA becomes transparent between 380 and 400 nm.
- UV-enhanced PMMA becomes transparent at 360 nm.



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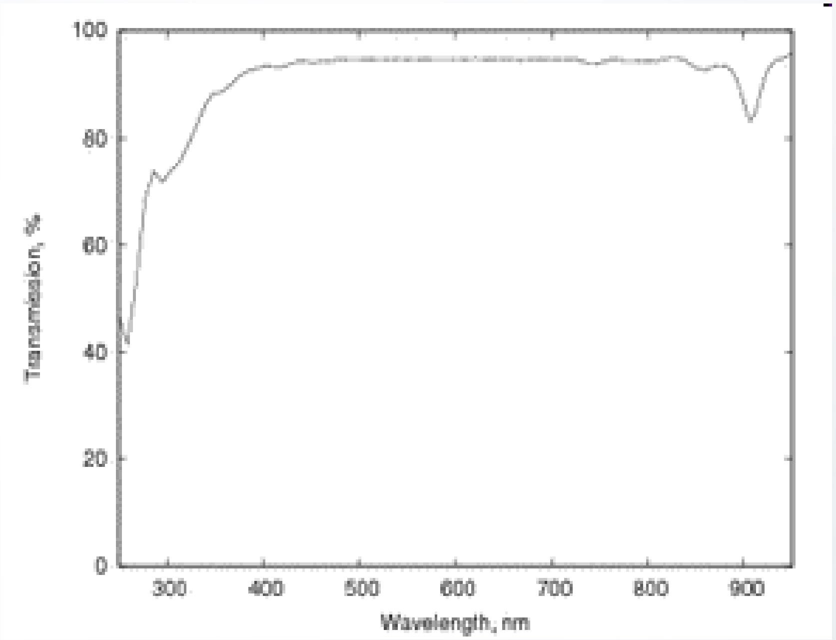
Transparency of SoG

- Silicone is more transparent in the UV part of the spectrum than PMMA.
- However, there is a significant drop in transparency in the IR part of the spectrum.



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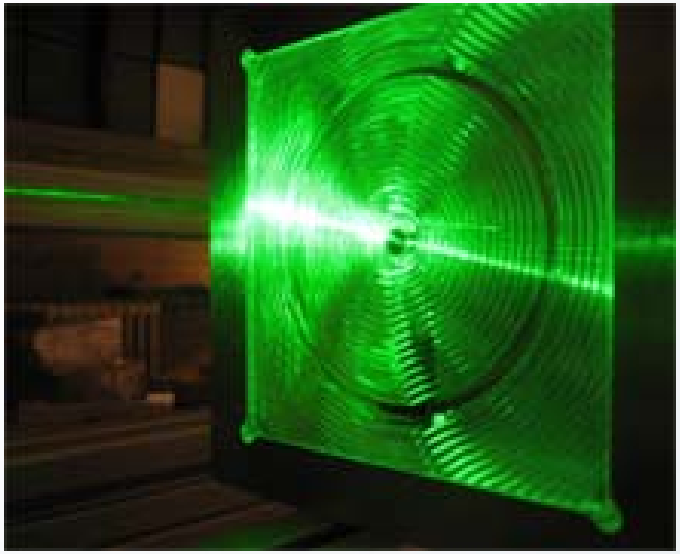
Secondary Optics

- Secondary optics are small aperture, small focal length lenses.
- They provide further magnification from the large area lens.
- Secondary optics are also used to compensate for dispersion.

Light-guide Solar Optic

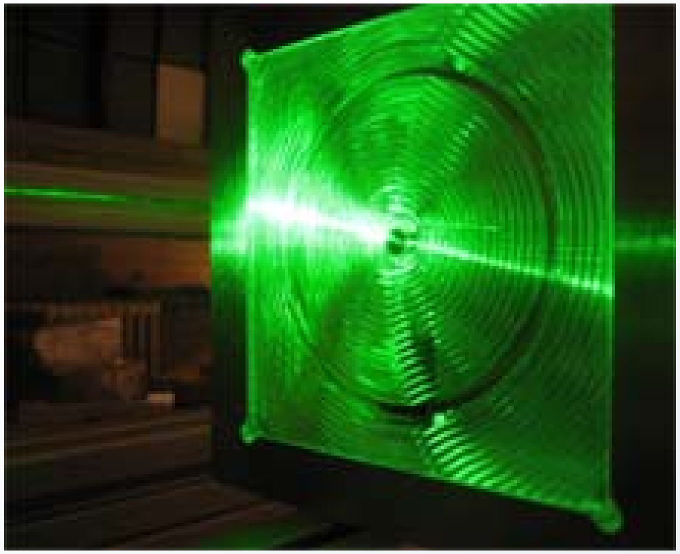
The light-guide solar optic (LSO) is not a lens but an optical waveguide (made of acrylic). It guides incident light to the center of the panel where a secondary optic (made of glass) further magnifies the light. The light is then emitted orthogonally out of the panel.



http://www.technologyreview.com/energy/22204/?a=f

Light-guide Solar Optic

Unlike other concentrating optics, the LSO has no focal length. The solar cell can be placed right up against the panel, greatly reducing the size of the system and eliminating the air gap.



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LSO Magnification

- In early 2009, the MIT Technology Review reported that the acrylic section of the LSO concentrated sunlight to 50 suns and the glass optic further concentrated the light to almost 1000 suns.

- Currently, Morgan Solar's website claims that the LSO can concentrate sunlight to 1400 suns.

http://www.technologyreview.com/energy/22204/?a=f

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High Efficiency Solar Cell

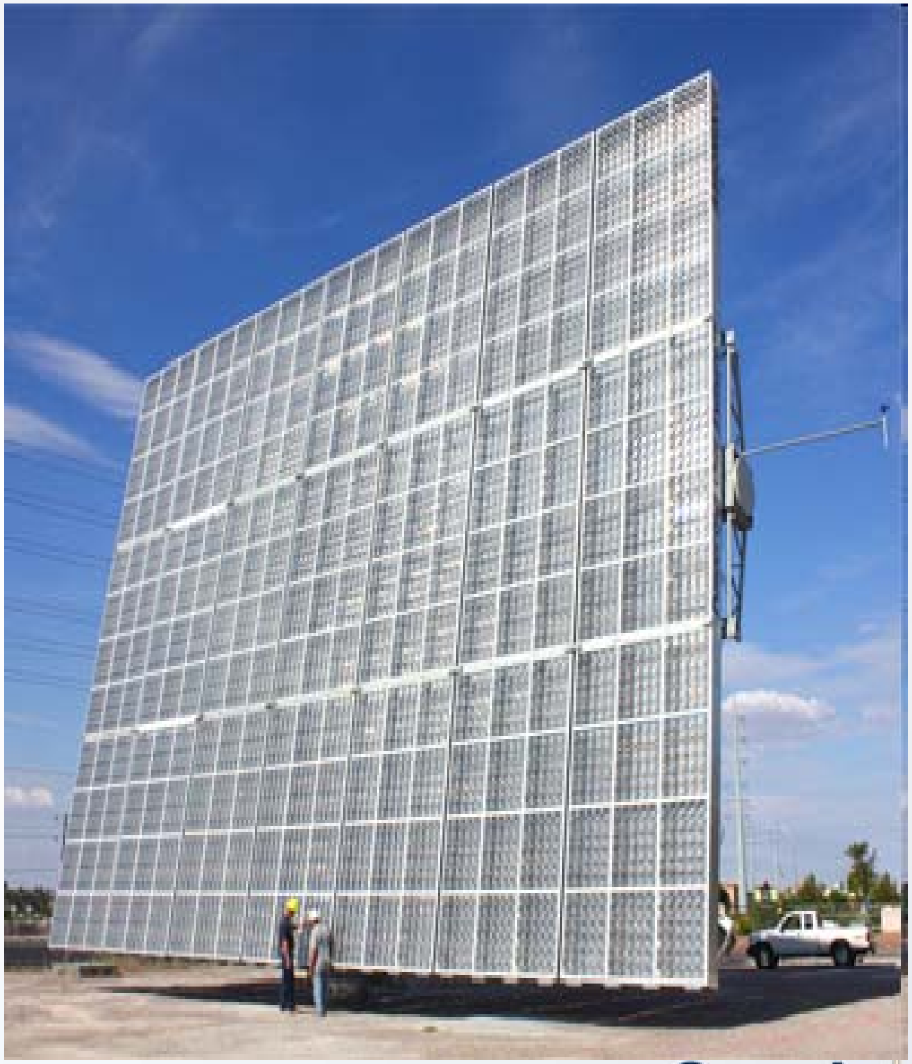
- HCPV systems typically use a III-V multi-junction solar cell. These cells are highly efficient but expensive. However, HCPV designers can make up for this cost because only a small area of solar cell is needed.

Tracking System

- HCPV systems require a very accurate tracking system because the light must be concentrated onto a small area of semiconductor.

Highlight System: Amonix 7700 Solar Power Generator

- The Amonix 7700 uses Fresnel lenses to concentrate light onto high efficiency solar cells.
- It generates an average of 53 kW of power during peak sun hours.
- It operates at 25% efficiency.



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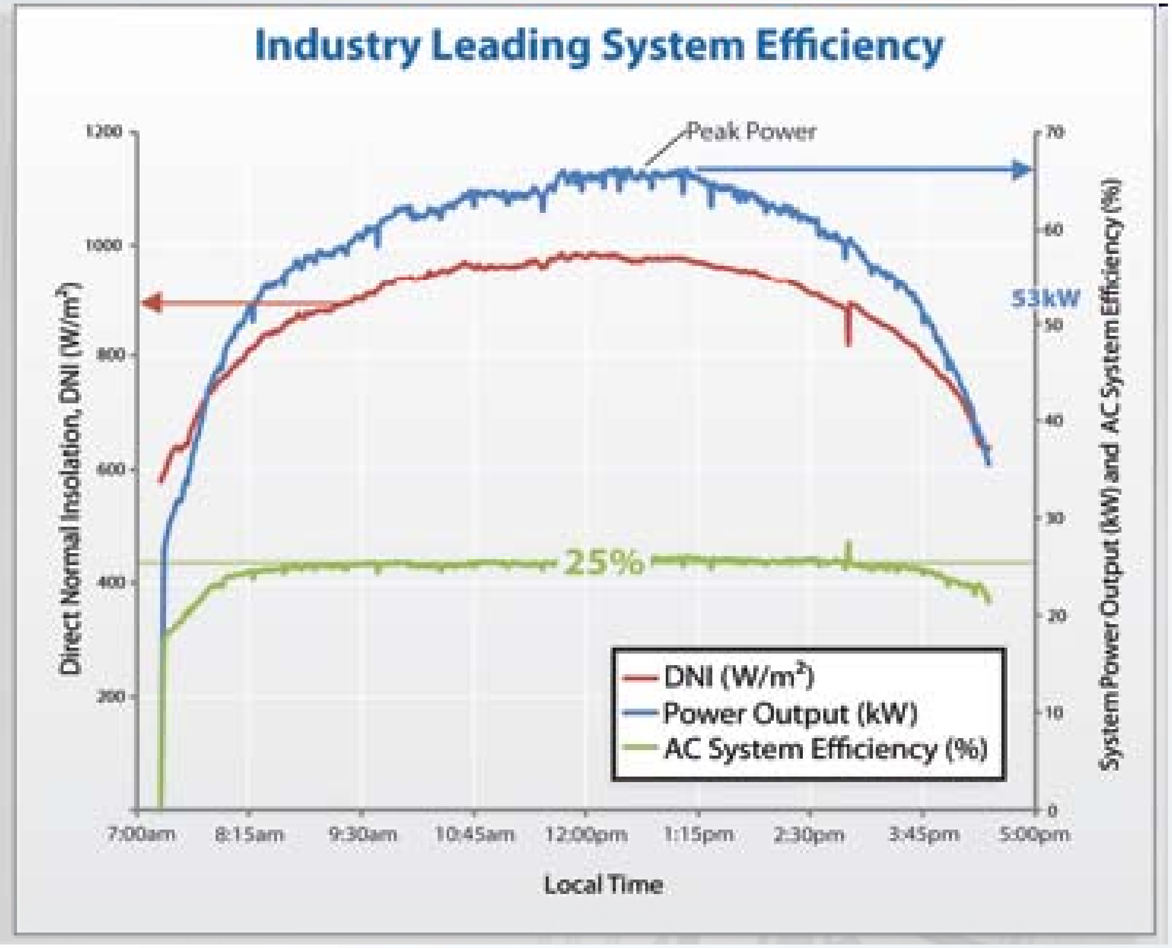
Amonix 7700 Solar Power Generator



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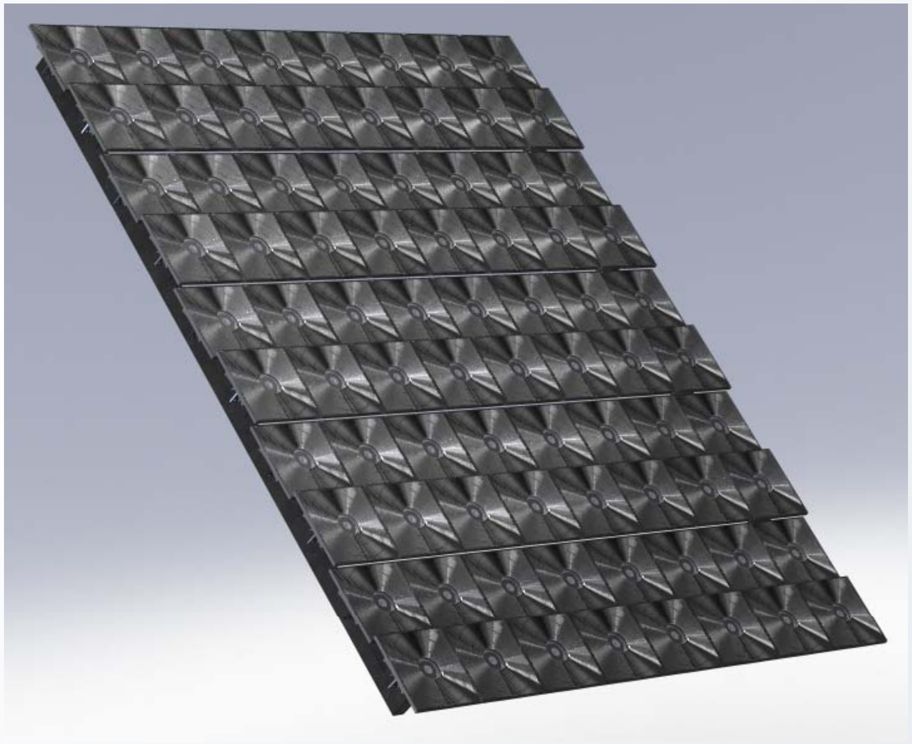
Amonix 7700 Specifications

- Sun tracking method: Closed Loop Sun Seeker
- Max operating wind speed: 28 mph
- Max wind loading: 90 mph
- Land area: approximately 5 acres/MW

http://www.amonix.com/products/index.html

Highlight System: Morgan Solar Sun Simba

- The Sun Simba uses the LSO to concentrate light into a multi-junction solar cell.
- The solar cell is bonded directly to the back of the LSO, making for an ultra thin system.



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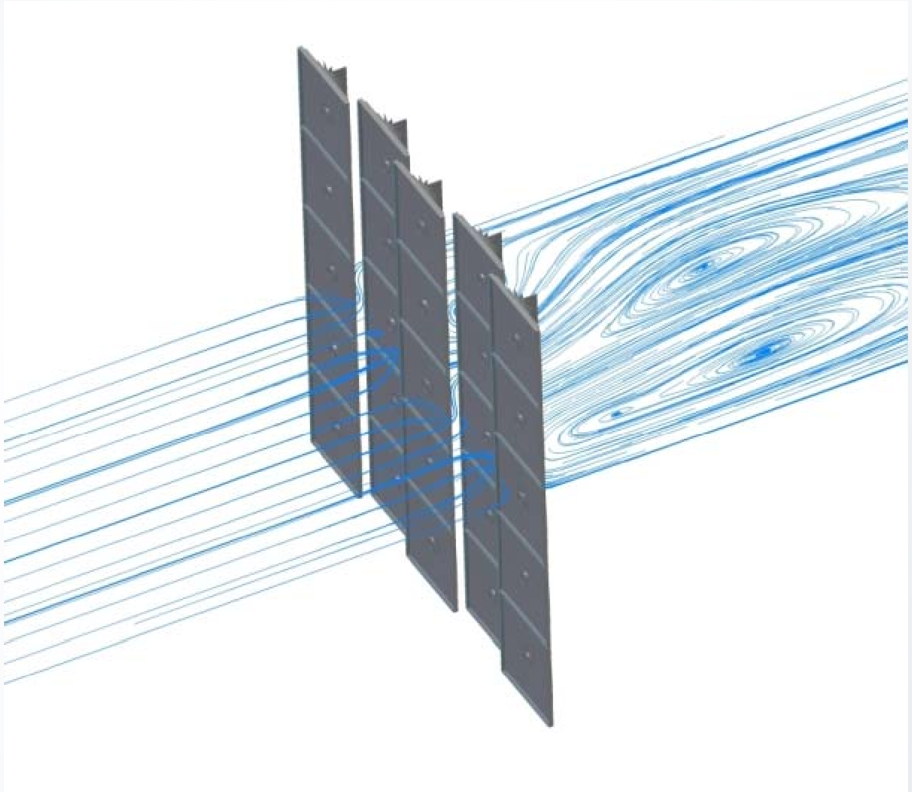
Staggered Row Design

- Because the panels of the Sun Simba are so thin, they can be placed at alternating heights. This is called a stagger row design.
- The staggered row decreases wind load.
- It also enables the system to cool itself more effectively using passive cooling.



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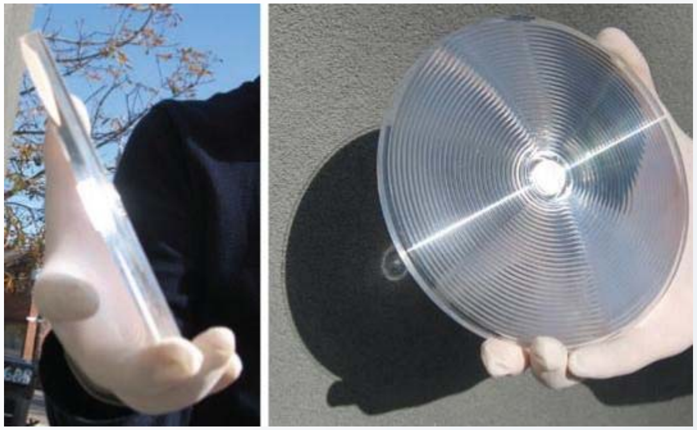
Encasement/Alignment

- Because the cell is directly bonded to the back of the LSO, both the LSO and the cell are encased in a transparent casing, protecting it from weather and humidity.
- In standard HCPV systems, temperature changes in the air between the lens and the solar cell can cause misalignments. The Sun Simba has no air gap, giving it a more stable alignment.



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Questions?