Holographic Concepts and Applications for Solar Energy Systems

Raymond K. Kostuk, Jose Castro, Deming Zhang and Brian Myer

University of Arizona

Tucson, Arizona

Glenn Rosenberg , Jose Castillo, Juan Russo

Prism Solar Technologies

Tucson, Arizona

Holographic Planar Concentrator Goal

- **Current Situation:** Solar Energy is abundant and capable of providing all the world's energy needs. However, it is still significantly more expensive than non-renewable energy alternatives.
- **Goal:** Reduce the amount of costly photovoltaic cell material and replace with low cost holographic collectors.

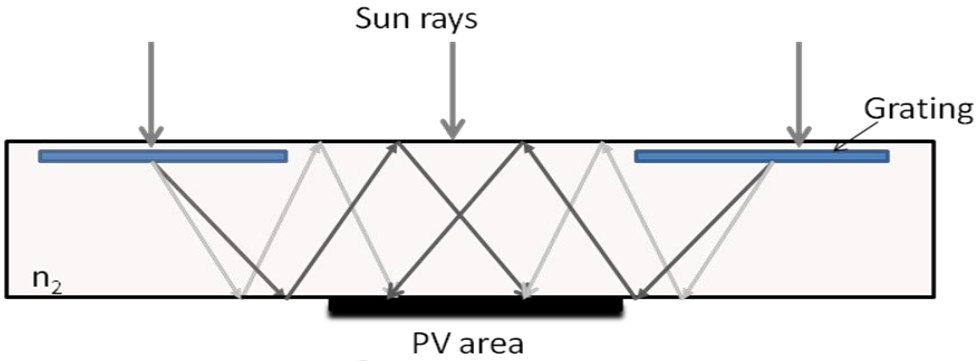
Holographic Properties Relevant to Solar Energy Collection/Concentration

- Bragg gratings – Single diffraction order with controlled angular and wavelength selectivity properties
- High diffraction efficiency (~100%)
- Spectral bandwidth – can be tailored for any PV cell-solar response characteristic from 250 nm – 2.0 μm
- Focusing power – can be incorporated in holograms
- Multiplexing – several functions can be combined in a thin film (~5-50 μm)
- Relatively thin layers can be laminated with other substrates
- Can be formed in large formats at low cost ~$4.00/$m^2$

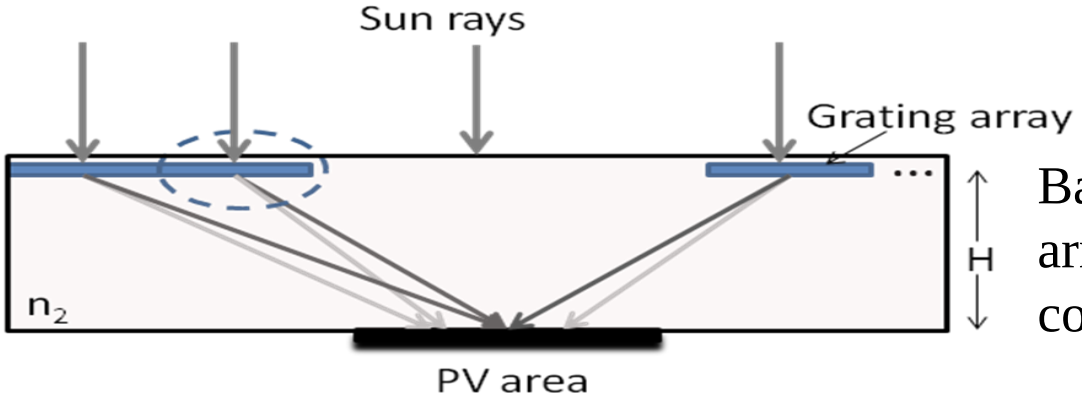
Holographic Planar Concentrator Concept

- Application to residential grid-tie photovoltaic systems
- Operates at low concentration levels (2-10X)
- Maximum collection angle without tracking
- Low profile package can be incorporated into standard photovoltaic modules
- Technique scales with evolving photovoltaic technologies
- Cost reduction – 50% of the cost of PV material (~\$1.5/W_p)

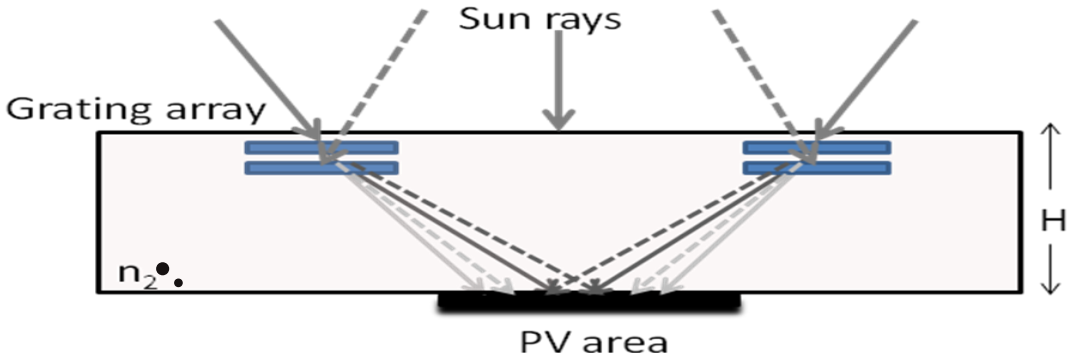
Examples of Holographic Planar Concentrators



Based on Total Internal Reflection

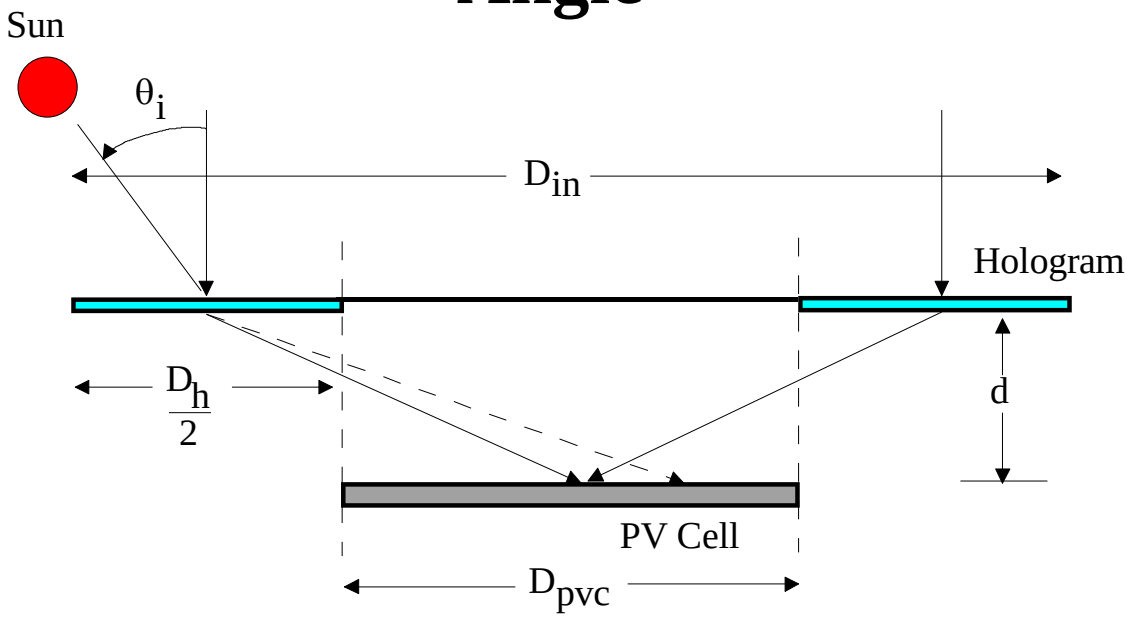


Based on lateral grating arrays to increase concentration factor.



Based on cascade gratings to increase seasonal collection angles.

Trade off: Concentration Ratio vs. Collection Angle



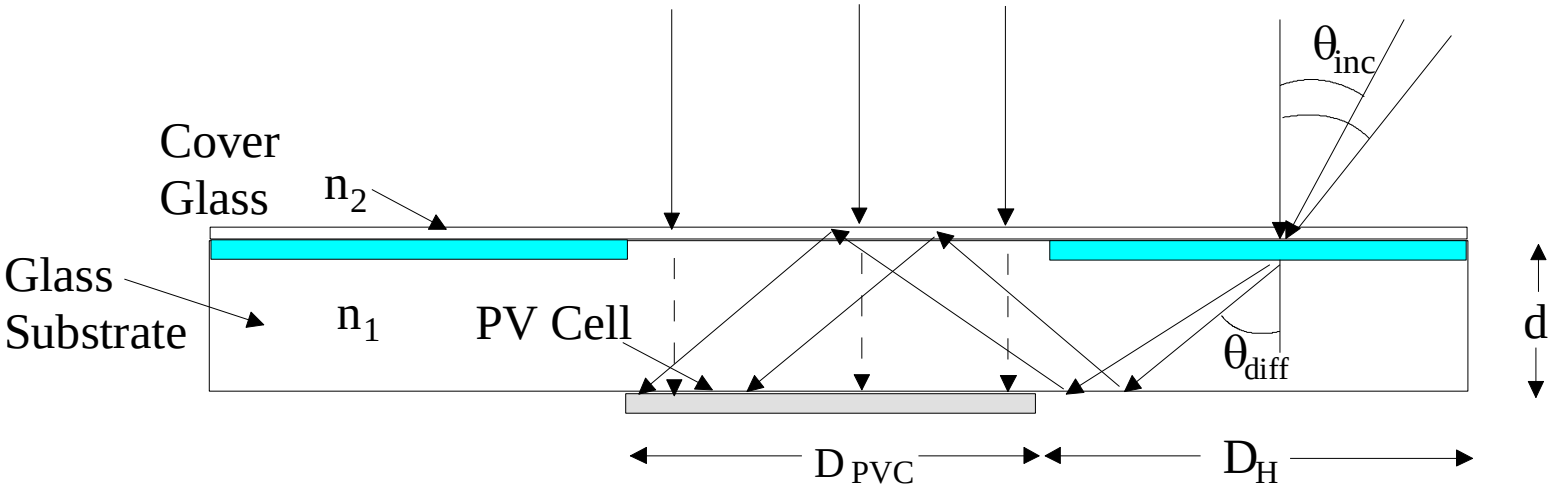
2D Concentrator:

$$C_{2D} = \frac{D_{in}}{D_{pvc}} = \frac{n}{\sin\theta_{in}}$$

With C = 2, n = 1.5: θ_{in} = 48.6° (half angle) without tracking.

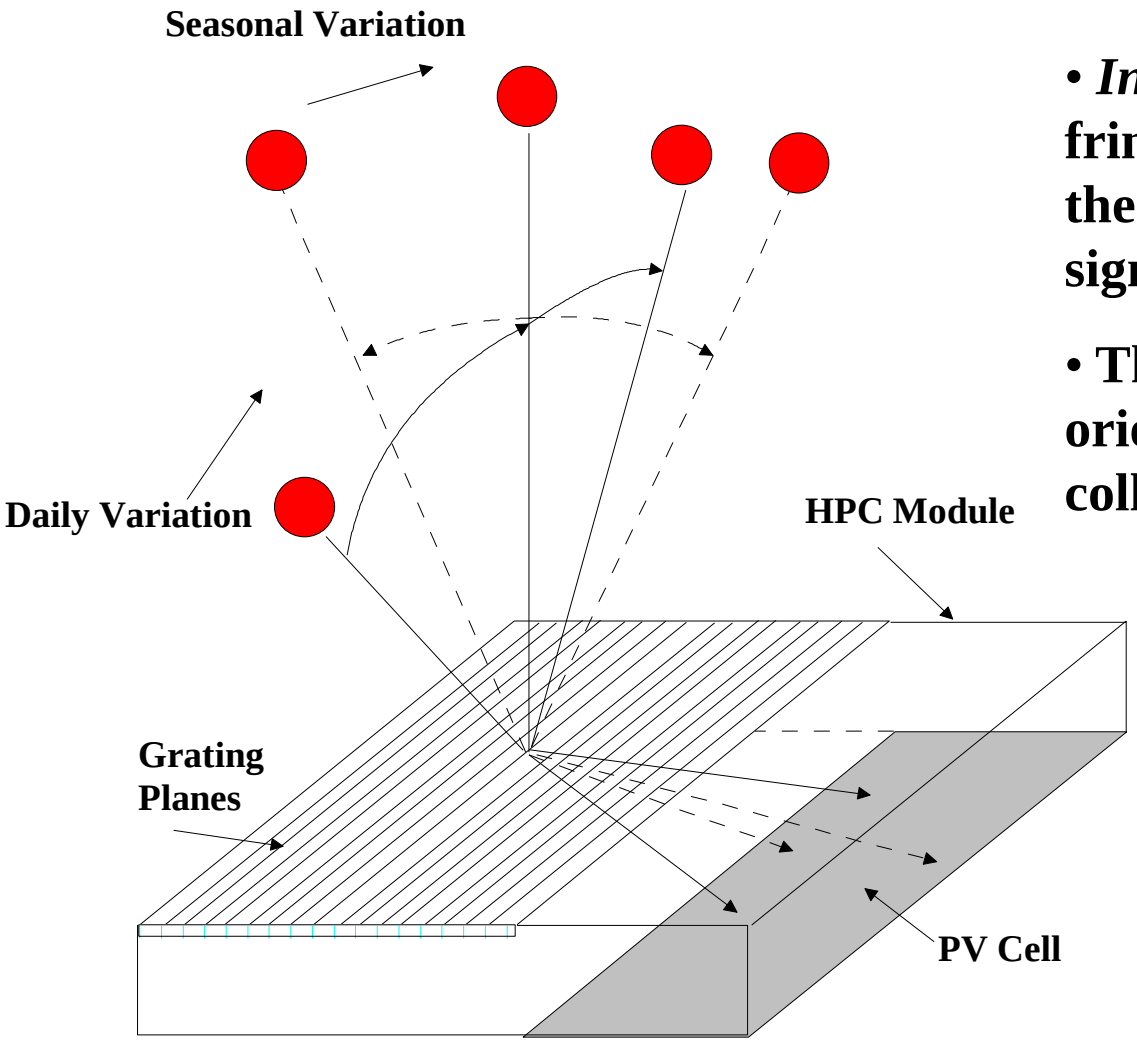
Angular acceptance range similar to CPC designs.

Holographic Planar Concentrator based on Total Internal Reflection



- **Light incident over a large range of angles are diffracted beyond the critical angle of the substrate.**
- **The substrate guides the diffracted light to the location of the PV cell.**
- **Light incident directly over the PV Cell is also collected.**

In-Plane and Cross-Plane Diffraction Efficiency

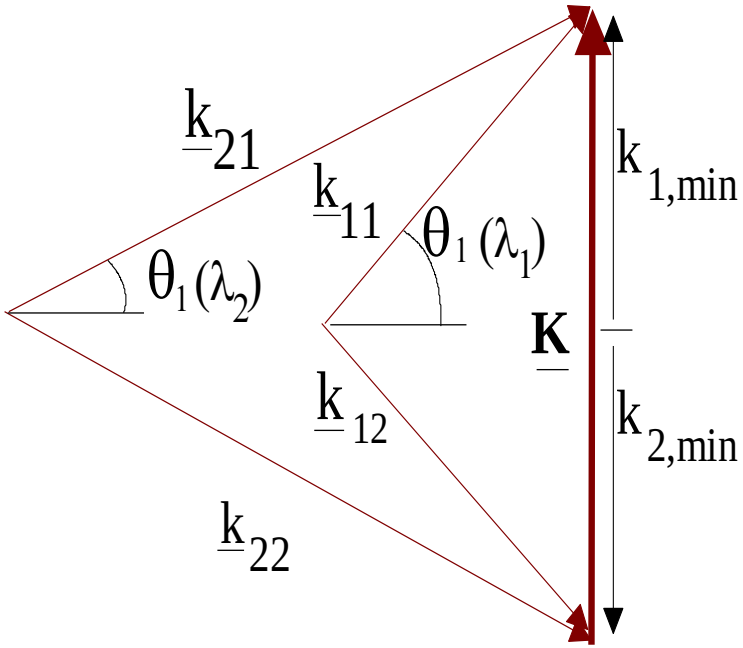


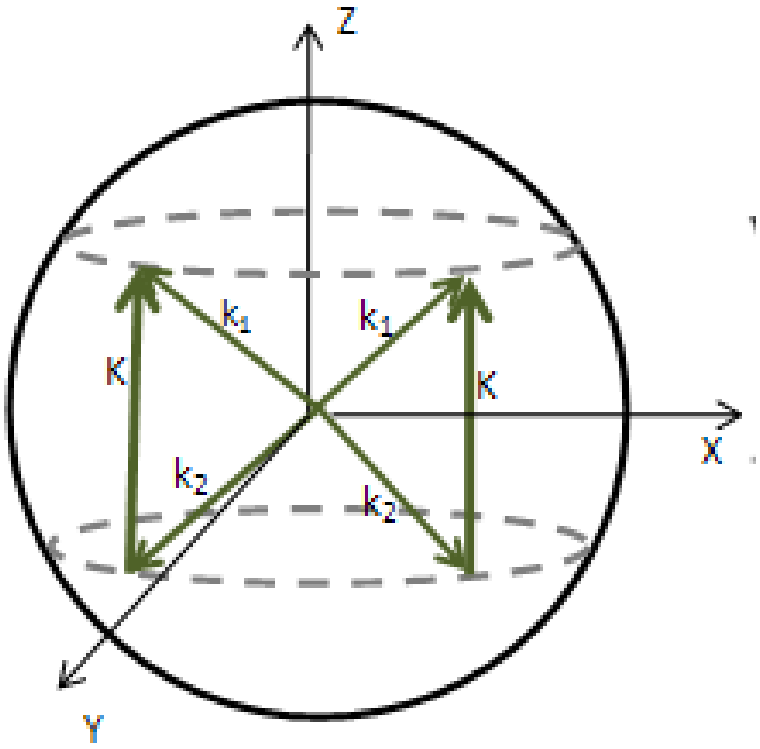
- ***In-plane*** **(⊥ to the grating fringes) and** ***cross-plane*** **(along the grating fringes) angles vary significantly.**
- **This will determine the module orientation for optimum collection efficiency.**

HPC Design Considerations

- Daily collection of HPC is possible over a large angular range 60^{o}-70^{o}.
- Seasonal collection angles $\pm$ 22^{o} is more of an issue.
- *Diffracted ray angles* and *diffraction efficiency* must be optimized for maximum solar collection efficiency.
- Angle-wavelength dispersion characteristic in conjunction with the solar-PV cell spectrum can be used to maximize the collected solar power.

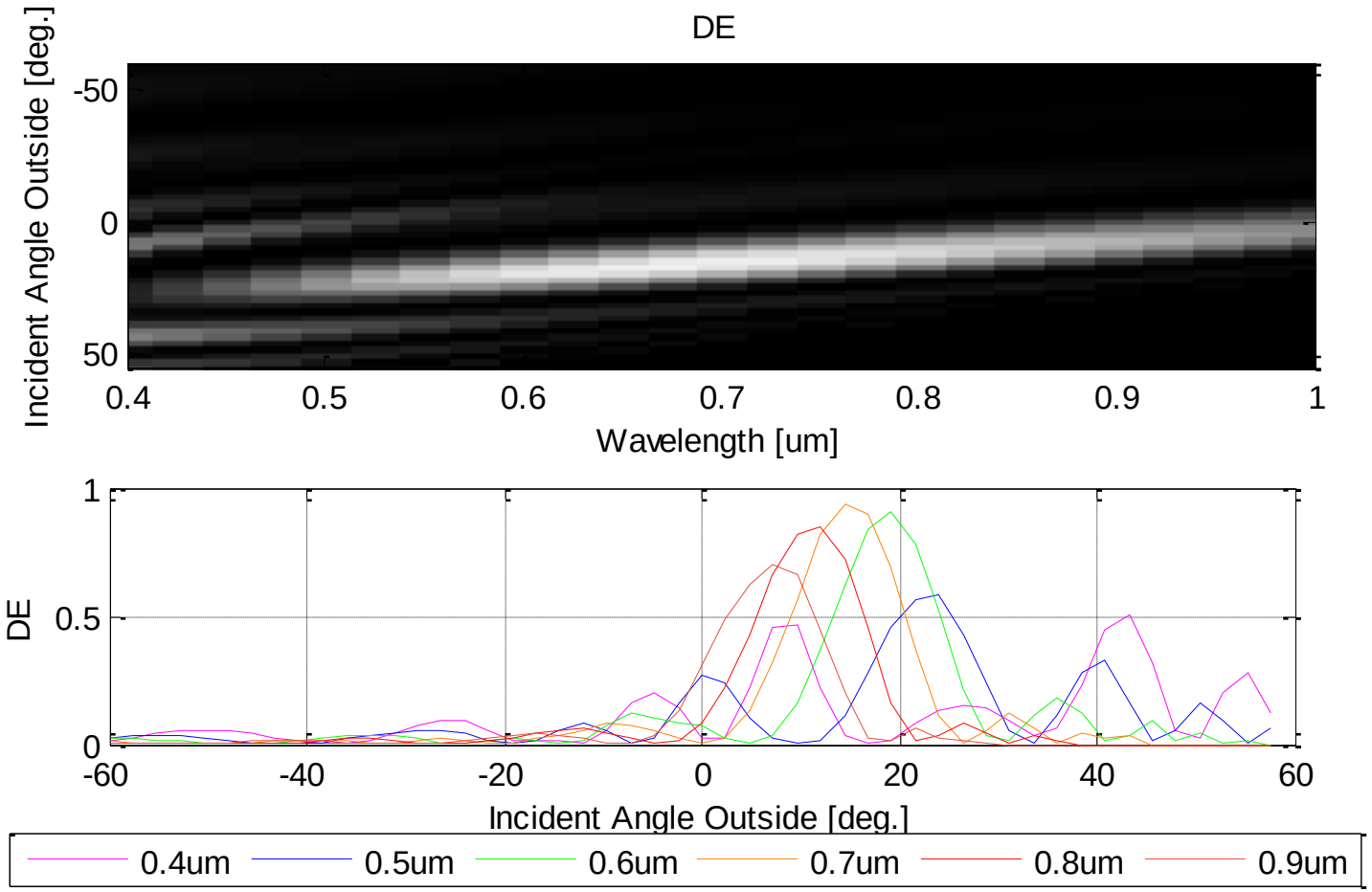
Angle-Wavelength Bragg Matching



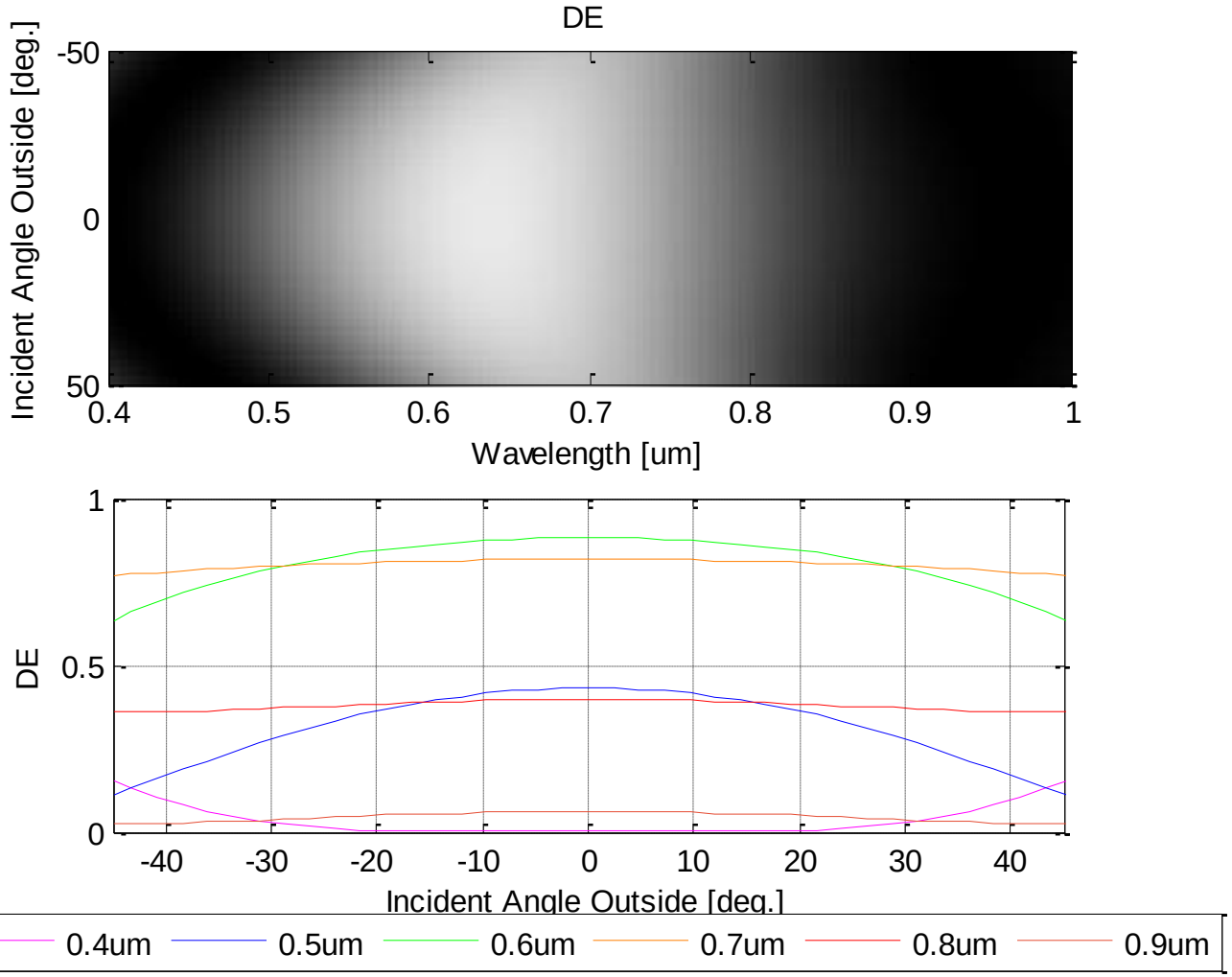


- **As the sun moves, different angles of incidence will match different portions of the solar spectrum.**
- **Bragg matching and high diffraction efficiency can be achieved over a broad range of angle-wavelength combinations.**

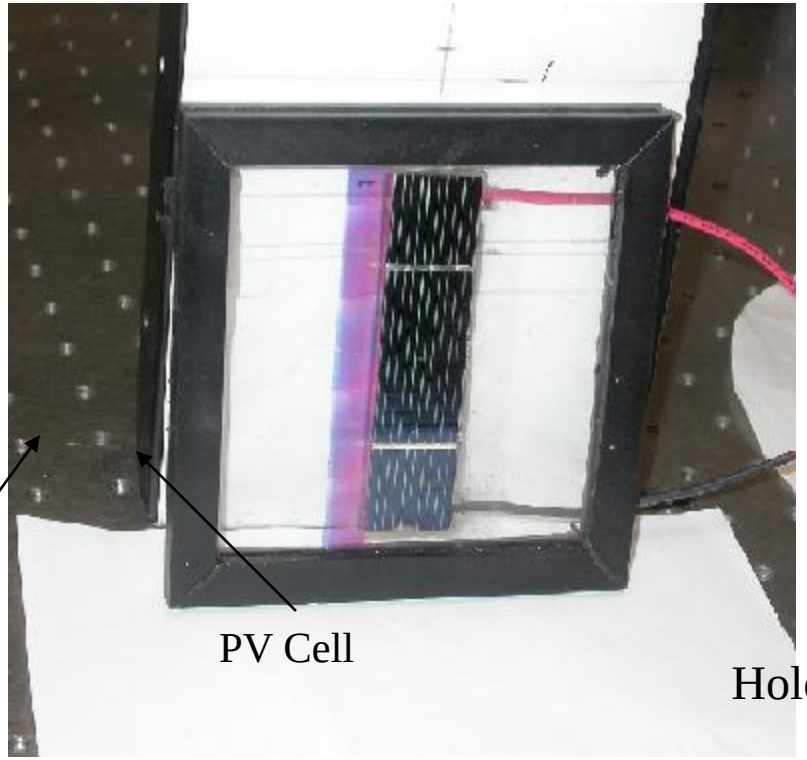
Transmission Hologram Spectral BW Shift with In-Plane Angle of Incidence



Transmission Hologram Spectral BW Shift with Out-of-Plane Angle of Incidence

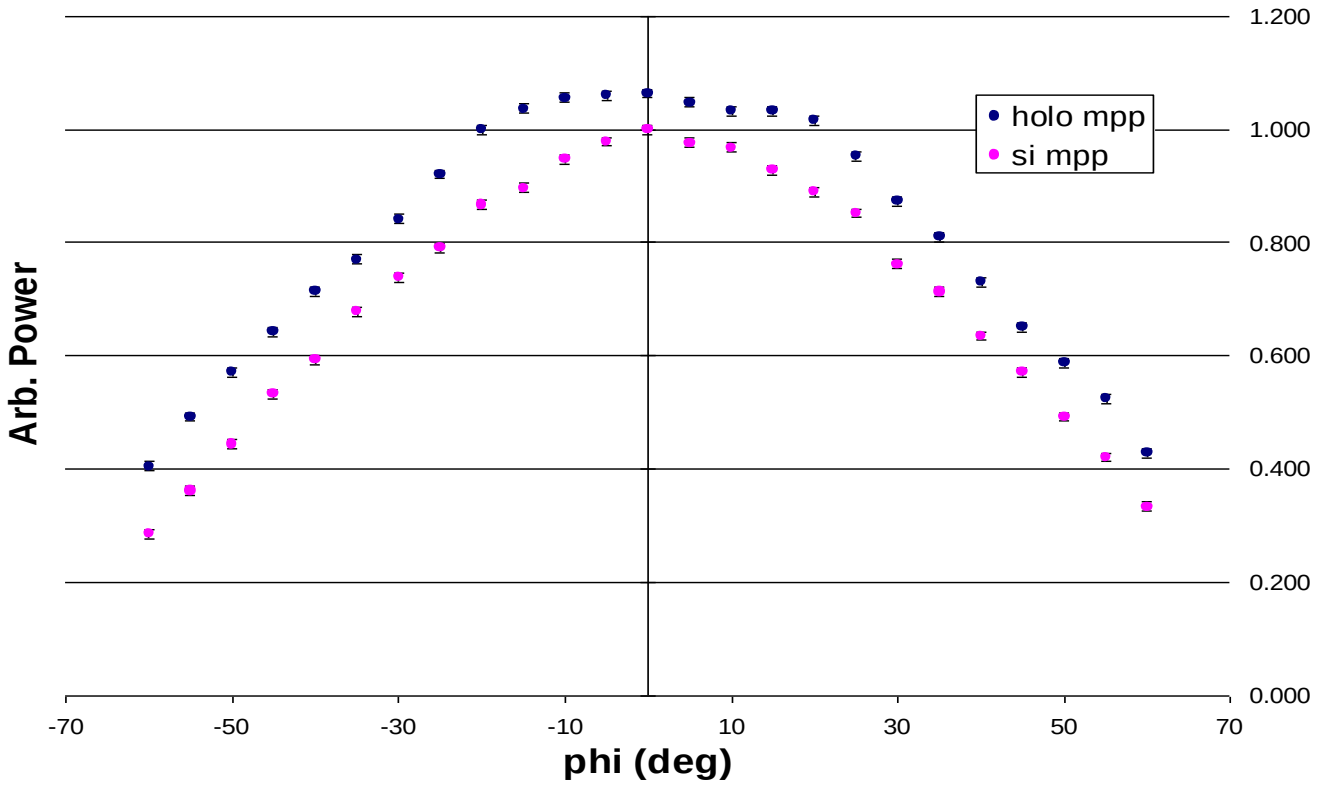


HPC Test Gratings-Modules



- **Hologram wavelength selectivity viewed at different `Seasonal' angles.**
- **Color shift indicates different spectral band selected by the hologram.**

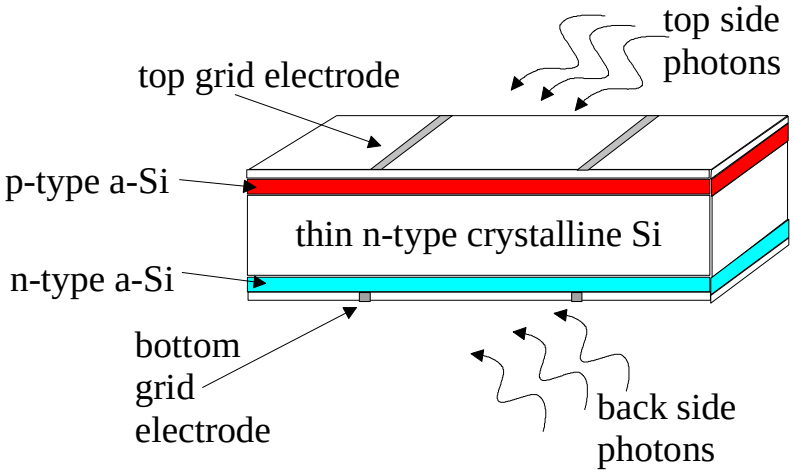
HPC Test Module Off-Axis Performance

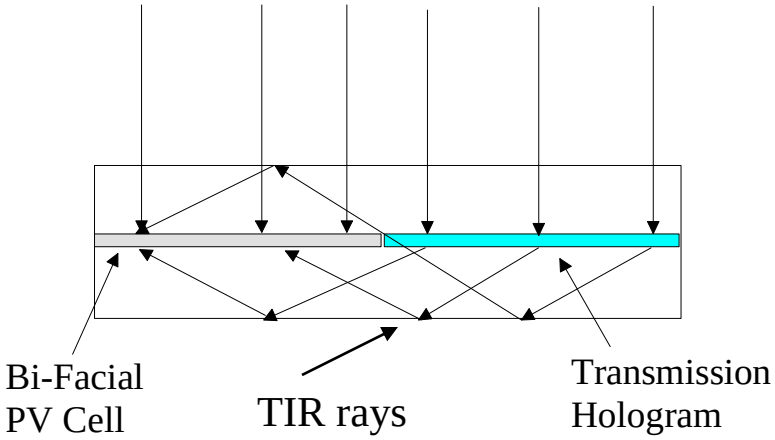


- Constant increase in maximum power point over $\pm 60^{o}$

- (Early HPC cell design with small area hologram and low diffraction efficiency. Latest HPC are currently being tested. Preliminary results indicate significant improvement)

Bifacial PV Cell and Mid-Plane HPC





- Bifacial PV Cell receives light from top and bottom surfaces of the cell.
- Bottom surface ~40% as efficient as the top surface. C = 1.4
- BF PV Cell can be integrated with a transmission or reflection holographic collector.
- Sanyo Heterojunction with Intrinsic Thin layer (HIT) bifacial solar cell (model HIP-186DA1)

Conclusions

- **Holographic concentrators provide a number of important advantages for solar modules including:**
  - **Reduced use of costly photocell material**
  - **Spectral selectivity to enhance the performance of PV cells**
  - **Ability to operate efficiently with both direct and diffuse sunlight**
  - **Passive tracking capability – due to low concentration ratios**
  - **Useful with existing and emerging PV cell technologies**
- **Orient grating planes in the direction of daily sun path for maximum collection efficiency.**
- **Preliminary demonstration modules have collection efficiency of 40%. Effective concentration ratio C ~ 2.45**
- **Improvements to hologram design should allow collection efficiencies of 50%.**
- **50% collection efficiency will reduce the cost of PV modules to ~$1.25/peak Watt based on a $40/ft^2 cost for silicon and $0.40/ft^2 for hologram costs. Estimates include module packaging costs.**