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An Approach Towards Light and Heat Management in PV Modules

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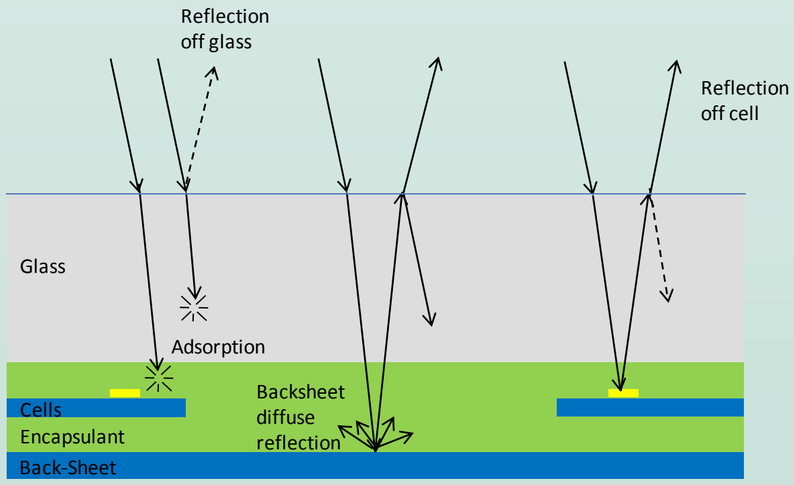
Motivation – Quantification of Optical and Temperature Losses

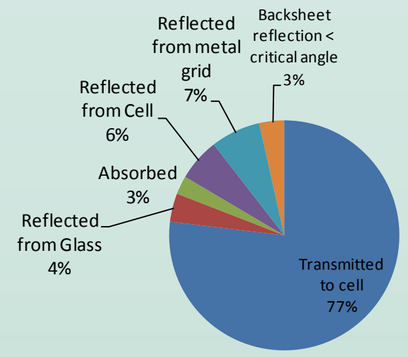
- PV Module energy output is limited by several factors on the module level.
  - Optical losses
  - Temperature losses
  - I^2R losses

Adsorber Type	Typical Temperature Coefficient % P_{max}/°C
mc-Si	-0.47
x-Si	-0.31
CIGS	-0.60
CdTe	-0.20
a-Si (triple junction)	-0.31

- Most modules have nominal operating cell temperatures (NOCT) in the region 50 to 60 °C
- Result is a significant loss in energy yield



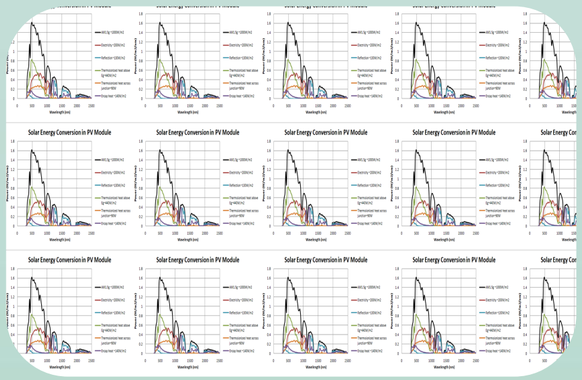
- A significant portion of light does not enter cells

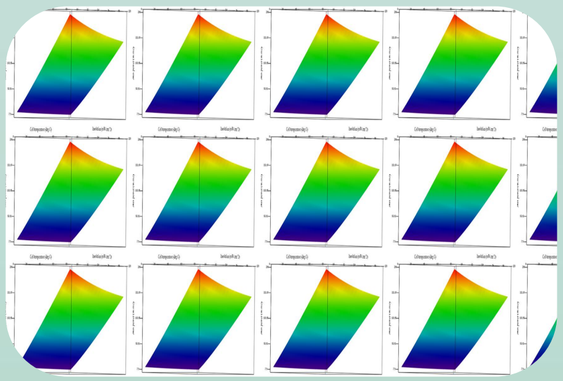


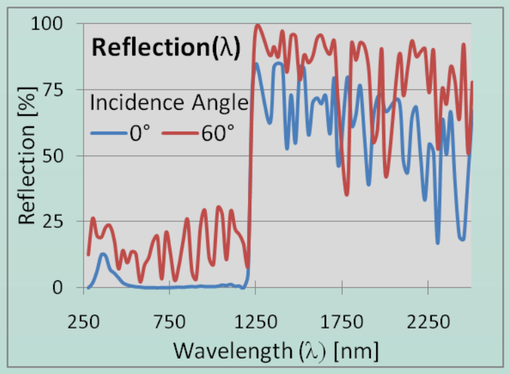
Assumptions: Incident sunlight, No ARC on glass, 4mm low Fe glass, 0.5mm EVA encapsulant, SiN ARC on untextured cells, 7.5% of cell area is metallization, 93% cell packing factor in module. Excludes frame and edges.
Note: Actual transmission to cell = 65% to >90% depending upon technology, architecture and orientation
References: S. Krauter, Solar Electric Power Generation, Springer 2005. K. McIntosh et al, 2009 PV IEEE, Philadelphia.

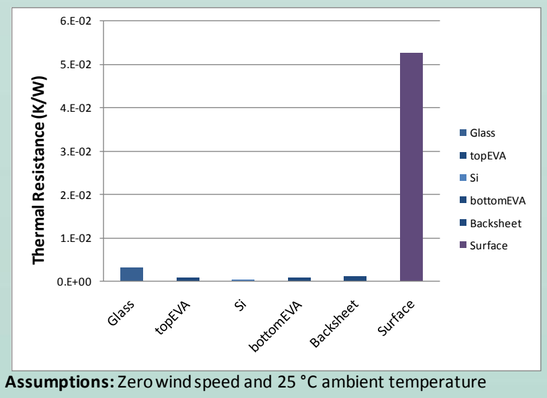
Computational Simulation and Testing of Solutions - Electromagnetic Wave Modeling

- Use computational model of electromagnetic waves from Maxwell's equations to predict light propagation and resulting energy dissipated in each layer.









Assumptions: Zero wind speed and 25 °C ambient temperature

- Optical losses are highly dependant on angle of incidence
- Greatest thermal resistance is at module surface

Experimentation - One Approach to Addressing Optical and Temperature Losses – Structured Glass

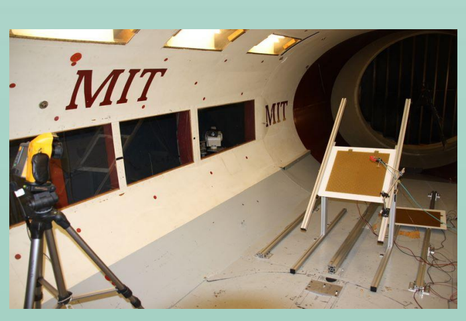
Module Temperature

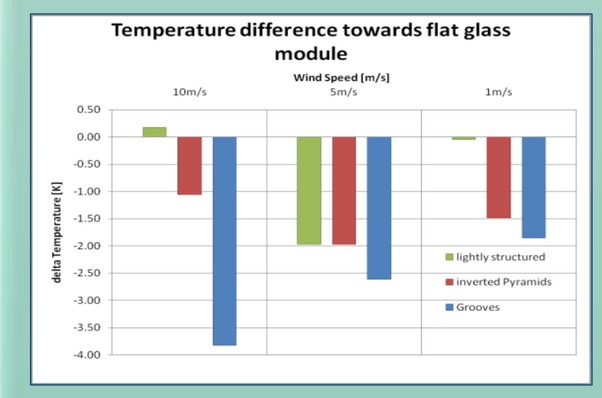
Module Fabrication

- Cells measured and sorted.
- Mini-modules assembled for the various glass structures using tabber –stringer and laminator
- Special modules fabricated that include foil heaters for wind tunnel testing.

Wind Tunnel Testing

- Constant power applied to heater in modules
- Module temperature measured as a function of wind speed and module tilt angle.

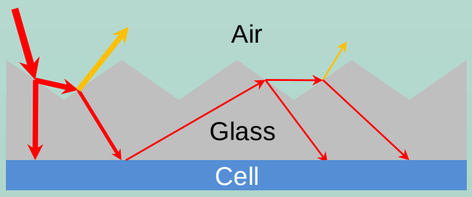




Results

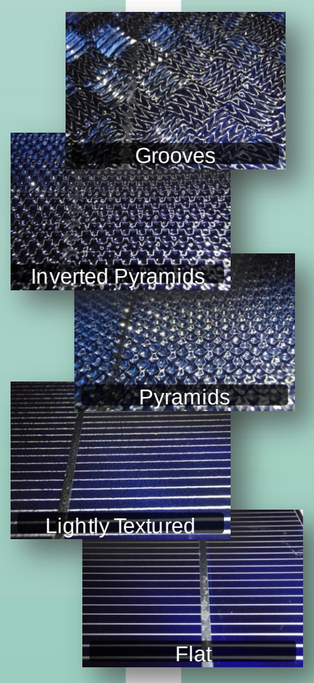
- Significant cooling observed for structured glass.
- Effect is highly dependent upon wind speed

Light Management



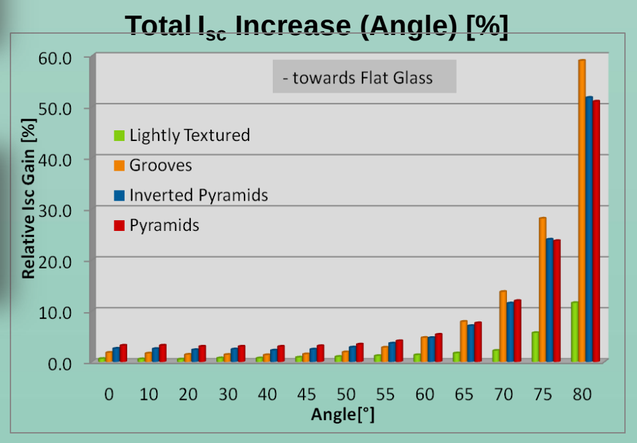
Theory

- Reflections are redirected by the structure, so that more light hits the cell.



Experimentation

- Module holder with tilt capability.
- Flasher with electronic load.
- Mini modules were tilted from 0˚ to 80˚
- I_{sc}, V_{oc}, FF, Eff. and angle were measured.



Results

- Structured glass has the has the capability of trapping more light.
- Effect becomes more pronounced at higher angles of incidence.