ARPA-E Workshop: High-Efficiency, High Concentration Photovoltaics Through Advanced Optical System Design

March 26, 2012
8:00AM – 3:30PM
Offices of Booz Allen Hamilton
3811 N Fairfax Dr, 6th Floor
Arlington, VA 22203

Objective

Identify technological whitespace, new research directions, and opportunities that could enable higher efficiency (> 60%) solar photoelectric energy conversion at a capital cost below $1/Watt by:

1. Developing advanced optical systems/components and management strategies that enable higher PV efficiency through spectral splitting.

2. Operating the optics and possibly the PV at high concentrations to minimize their capital cost ($/Watt).

Introduction to the Workshop

The majority of research funding in photovoltaics (PV) has focused on improving cell and module efficiencies and lowering their cost. In concentrated PV (CPV), however, the cell and module costs no longer dominate the total system cost. Instead, the major costs are associated with gathering and injecting the concentrated light into the PV cell itself. Aside from Fresnel lenses and parabolic reflectors, it appears that other approaches for gathering, concentrating and preconditioning light exist and will have a different set of technical challenges and tradeoffs. If such approaches prove fruitful it could put CPV on a fundamentally new learning curve. Determining if there are new and potentially less expensive (lower $/Watt) ways of getting the light into the cell is the primary purpose of this workshop, rather than pushing for higher cell efficiencies with broad band light input. The second objective of the workshop is to determine what metrics would make sense in the event that a funding opportunity announcement (FOA) is created.

The fundamental problem in PV conversion is that the sun emits broadband light and a PV cell provides electrons at a single voltage. PV cells can be highly efficient > 90% at converting photons above the band gap to electron hole pairs. Photons with energies much higher than the band gap, however, are still collected at a voltage close to/below the band gap energy and the rest of the energy is dissipated thermally. Since all the broad spectrum photon energy in a single band gap cell is collected at one voltage, these cells are fundamentally limited to ~ 34% efficiency. Multi-junction cells try to mitigate this loss by using multiple band gaps in series to cover more of the spectrum (vertical spectral splitting). Multi-junction cells, however, have to be lattice and current matched at each interface, which limits the number of band gaps that can be included in a single cell. Furthermore, the current matching constraint leads to a significant efficiency penalty in actual operation, because the solar spectrum changes throughout the day.

An alternative way to increase the efficiency is to separate the photons before they reach the PV cell. Such an approach is generally more complicated, involving more components and if operated at low concentrations, it can be more expensive with minimal benefit. This may not be the case, however, if the spectral splitting is done at high concentrations and is optimally exploited to make the conversion more efficient. Accordingly, one potential way to decrease the system costs is to use cheap first layer collection optics and to shrink the size of the more expensive high performance components whose costs generally scale with area ($/m^2), which can be accomplished by operating them at higher concentrations. Since light is self-propelled and can be concentrated without the requirement of auxiliary energy input, it is most economical to use inexpensive optics at the lowest levels of concentration (largest area), and more expensive optics at the highest concentrations/smallest area. From an economic standpoint, this means that the added expense of additional optics for lateral spectral splitting only makes sense if the high performance optics have considerably smaller area than the first layer collection optics and if the number of band gaps employed in the cells were to go beyond the limits of multi-junction cells (~3-5 junctions). This regime (~6-15 band gaps), however, has yet to be explored and we think this direction may be a breakthrough for CPV, if successful.

Workshop Agenda

Start Time	End Time	Activity	Speaker(s)/Officiate
8:00	8:10	Intro to ARPA-E	Dane Boysen (ARPA-E)
8:10	8:25	High-efficiency, high-concentration photovoltaics through advanced optical system design - workshop overview	Asegun Henry (ARPA-E)
8:25	8:50	CPV a review	Dan Friedman (NREL)
8:50	9:05	Spectral Splitting Approaches - A review	Michael Piszczor (NASA)
9:05	9:20	Systems level challenges	Roger Angel (Univ. Arizona)
9:20	9:35	CPV with photonics	Peter Bermel (Purdue)
9:35	9:50	Optical management for CPV	Dennis Prather (Univ. Delaware)
9:50	10:00	Coffee Break	
10:00	12:00	Break out Session 1	
		PV Cells Optimized For Narrow Bandwidths of Light	Timothy Heidel (ARPA-E)
		Optical Systems Design	Philippe Larochelle (ARPA-E)
12:00	1:00	Lunch	
1:00	2:00	General Session - Where is the white space	Asegun Henry (ARPA-E)
2:00	2:10	Coffee Break	
2:10	3:10	General Session - What are the important metrics?	Asegun Henry (ARPA-E)
3:10	3:30	Wrap Up	Asegun Henry (ARPA-E)

Ground Rules

In the interest of time, the following topics will not be discussed:

1. Regulations, policies, subsidies and demonstration projects with existing technologies
2. Incremental improvement strategies to existing technologies
3. Ideas that would only accelerate down existing learning curves
4. Methods of increasing PV cell efficiency that do not involve optical management

ARPA-E's goals are to:

1. Validate or improve our ideas on appropriate metrics. We seek to be technically audacious, but set targets that are achievable with sufficient effort.

2. Identify and understand potential new designs, materials, and fabrication processes that could result in dramatically more efficient CPV systems.

GROUP 1: PV Cells Optimized For Narrow Bandwidths of Light

Group 1 Breakout Session Questions:

1. How would single and multi-junction cell design change if the cells were only designed for narrow band widths (i.e. 400 nm – 600 nm)?
2. Are there optimal bandwidths? If so, where, how wide and why?
3. Can cells be designed for optimal operation at > 1000X concentrations?
4. What are the important metrics for determining if a proposed spectral splitting CPV system could eventually cost < $1/Watt?

GROUP 2: Optical Systems Design

Group 2 Breakout Session Questions:

1. What are the most promising approaches in optics that could yield highly efficient spectral splitting and enable > 6 band gap PV conversion? What aspects are the most technically challenging?
2. Are there schemes that could allow us to concentrate light to ~ 10,000X and do spectral splitting at the highest concentrations? Are there new ideas for integrating the thermal management strategy into the optical component/system design?
3. If you assume the cost of PV cells is ~ \$500/m^2 for single junction and \$100,000/m^2 for multi-junction and that they have flat EQE profiles ~ 90% and can be made with any band gaps desired -- How would you design an optical system using these cells that can achieve > 60% light to electricity conversion efficiency (neglecting first layer collection losses) and below $1/Watt-e?
4. What are the important metrics for determining if a proposed spectral splitting CPV system could eventually cost < $1/Watt?