Advancing Photovoltaic Technology Through Measurement Techniques

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Crystalline silicon technology has made great strides over the years and currently dominates the commercial photovoltaics market. Improvements in power conversion efficiency (PCE) and module manufacturing capability continue to offer possibilities for future performance gains and cost reductions. In addition, the next-generation technologies including advanced thin film, crystalline multijunction, organic, and nanostructured photovoltaics all hold promise for potentially disruptive improvements in performance or cost. For a number of these photovoltaics technologies, the potential exists to approach or even exceed the performance of silicon in commercial applications. Although these next-generation technologies currently operate well below their theoretical PCEs, dramatic gains are possible if key problems can be solved.

This workshop will examine the technical barriers limiting crystalline silicon performance as well as those impeding the development of advanced, next-generation technologies. *The goal of the workshop is to identify all potential technical barriers, and describe the knowledge gaps that complicate solutions. A special focus will be on identifying current and future measurement capabilities that can fill in these knowledge gaps.* World experts in each of these areas will meet to present the most current status and challenges that these technologies face in the future. Breakout sessions will be used to discuss these challenges and identify the most promising paths to solutions. The resulting report from this workshop is expected to guide the developments that enable an acceleration in the pace of photovoltaics performance improvement and cost reduction.

The challenges and needs of the following PV technologies will be considered and discussed:

- **Wafer-Based Crystalline Silicon PV:** Crystalline silicon holds as much as 85% of the commercial PV module market. Its future appeared to be limited when the cost for polysilicon skyrocketed a few years ago. Since then polysilicon costs have more than halved, returning crystalline silicon to an increasing market share position. Associated with its reemergence, much development work is ongoing to reduce costs still further. These activities generally address increasing the PCE of standard cells from 16% to as high as possible with improved processing techniques and cell structures. Also there is a need for further reductions in manufacturing costs through improvements in production yield and module encapsulation. Advanced measurement tools and techniques are required in all of these areas.
- **Amorphous Silicon and Polycrystalline Thin Film PV:** The dominant technologies are CdTe and multi-junction thin film silicon, which are the most mature and exhibit small area cell PCEs approaching 14% and 16.5%, respectively. CIGS is less mature but has the advantage of higher PCE (near 20%). For all three technologies, there exist opportunities for further improvement. Challenges in these technologies include using thinner absorber and window layers, developing higher rate and atmospheric pressure deposition techniques, improving uniformity and control of stoichiometry over large areas, designing new multijunctions, narrowing the gaps between cell and module PCEs, identifying stability issues (from materials to contacts, and water ingress), addressing materials availability/cost issues, environmental concerns, and recycling. Thin films are classified as 2nd Generation technologies, but they are showing great promise as disruptive technologies to crystalline Si PV because of their transformational and technology-driven nature.

- **III-V Multi-Junction PV:** PCEs in the range of 40% are currently achieved in triple-junction solar cells under concentrated solar illumination. There are many core technological challenges, some related to the extreme illumination conditions and others related to concentrators. These include non-uniform illumination, localized heating, solar spectrum modification, current matching for different solar spectra, series resistance, and materials and device fatigue/reliability.
- **Excitonic and Quantum-Structured PV:** This session includes discussion of solar cells whose absorber layers rely on quantum physics (i.e., confined excitons). At least three different excitonic and quantum-structured solar cell technologies are currently being explored: organic-based, dye-sensitized, and quantum dot/wire technologies. Such solar cells exhibit laboratory PCEs of up to 11%. Numerous challenges exist, both fundamental and technological, to achieving broader commercialization. These include a fundamental understanding of the complex microstructure, photophysical processes, charge separation, charge transport, electronic structure/trapping, contacts and series resistance, spectral matching, and materials and device stability. Other technological challenges include development of processing-property relationships among the molecular structure / microstructure / device performance, and the lack of existing manufacturing base / infrastructure and data on long-term reliability. In general, there is a lack of theoretical models on all levels from device physics to materials processing.

Cross-cutting: In addition to the quantum-structured PV applications covered under the Excitonics session, nanoscience and technology will be a potential cross-cutting issue for discussion in other breakout sessions. These will likely emphasize applications where the nanoscale phenomena are secondary to device physics (e.g., light capture, contacts). Advances in nanotechnology have many applications in the PV industry that could increase performance, among other benefits. Two primary cross-cutting approaches are likely: (1) semiconductor quantum structures, such as quantum dots and wells, which may be embedded/incorporated into traditional semiconductor systems (in particular, thin Si and III-V's) to tailor and enhance their performance; and (2) nano-engineered structures, such as carbon nanotubes and nanowires which may also be integrated into contacts and other non-semiconductor components. The use of nano-engineered structures allows one to tune / expand the spectral response, enhance the local fields, excite multiple excitons from a single photon, or upconvert infrared photons, thus providing possible routes individually or in combination toward substantial (revolutionary) gains in PCE.

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