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Solar Energy Technologies Program

National Solar Technology Roadmap:

Sensitized Solar Cells

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National Solar Technology Roadmap: Sensitized Solar Cells

Scope

This roadmap addresses sensitized nanostructured solar cells, which include both hybrid organic/inorganic and entirely inorganic structures.

Technology development stage: The first manufacturing plant (G24I) to produce sensitized solar cells on a commercial scale began operations in 2007. Proof of concept for more-efficient versions.

Target applications: At this time, applications that can tolerate ≤10% efficiencies in return for very low cost. More advanced concepts are aimed at high-efficiency applications, as well. This technology has special potential for electricity-generating/conserving windows and other building-integrated photovoltaic (BIPV) components, and for lightweight portable power-supply charging devices for consumer electronics and military applications (e.g., mobile telephones and military garments).

Background

One of the current versions of sensitized solar cells is the liquid-electrolyte-based dye-sensitized solar cell (DSSC), which was developed in the 1990s. Certified efficiencies exceeding 11% have been demonstrated for laboratory cells (Sharp) and 6%–7% for modules. Tandem versions of the cell have reached 15% conversion efficiencies. Recent research has greatly improved the stability of these cells. Sensitized cells can also be completely solid-state.

Sensitized solar cells, in some of their forms, have considerable advantages over other technologies: (1) They are very tolerant to the effects of impurities because both light absorption and charge separation occur near the interface between two materials and that interface area can be quite extensive (e.g., >1000 times the projected area) for a given footprint; (2) This relative impurity tolerance and simplicity allow for easy, inexpensive scale-up to non-vacuum- and low-temperature-based high-volume manufacturing via continuous processes (e.g., screen-printing, spraying, pressing, or roll-to-roll production); (3) The materials are inexpensive and effectively limitless (e.g., a common semiconductor employed is widely used in toothpastes, sunscreen, and white paint); (4) They operate optimally over a wide range of temperatures; (5) Their efficiency is relatively insensitive to the angle of incident light; and (6) The range of applications are numerous because the sensitizer can take on any color with a full range of transparencies and can range from ultraviolet to infrared. This allows for building-integrated windows, walls, and roofs of varying color and transparency that will simultaneously generate electricity even in diffuse light or at relatively low light levels in addition to whatever other function they serve. Cells can be made on lightweight and flexible (G24I, Konarka) or rigid substrates (e.g., plastic, fabric, metal, glass, and ceramic).

Similar to the current U.S. Department of Energy (DOE) effort to make funding decisions among existing solar electric technologies, the Netherlands Agency for Energy and Environment conducted a comprehensive technological evaluation of thin-film solar cells as referenced to multicrystalline silicon (see R. McConnell, "Assessment of the dye-sensitized solar cell," *Renewable and Sustainable Energy Reviews*, **6**(3), Sept. 2002, pp.271–293). Using DOE criteria, the overall conclusion of the review was that the DSSC faired better than all the rest of the technologies, except for thin-film silicon. Further improvement in DSSCs has transpired since this evaluation.

At NREL, basic research on sensitized solar cells has been funded by the Office of Science (OS) and cell development has been funded by the Office of Energy Efficiency and Renewable Energy (EERE) under a joint R&D program between the two DOE organizations since 1996. The OS-supported basic science on the fundamental mechanisms of sensitized solar cells has been applied to the EERE-funded development of improved solar cells; thus, NREL produces the best-performing sensitized solar cells in the United States.

Roadmap Overview

Although the stability and light-conversion mechanisms are inadequately understood at this time, it can be said that (1) there is no expected limitation on material, (2) stable 10%-efficient modules are certainly within reach, and (3) the energy-payback period should be significantly shorter than other PV technologies; this is especially important with forecasts of ever-increasing energy costs. As evidence of chemical and thermal robustness, recent accelerated aging tests showed that ≥8%-efficient laboratory DSSCs retain 98% of their initial performance over 1000 h when subjected to thermal stress (80ºC) in the dark *or* when exposed to both thermal stress (60ºC) and continuous light-soaking over 1000 h. Outdoor tests (Toyota/Aisin) of first-generation DSSC modules have shown less than 15% degradation in 4 years. These results and others inspire investment in the technology, and several companies are working toward commercializing this technology.

A 2005 DOE assessment (see www.sc.doe.gov/bes/reports/files/SEU_rpt.pdf) concluded that by developing the scientific underpinning to exploit the unique properties of sensitized systems, an efficiency of 20% is attainable, and that such studies may further lay the scientific foundation for developing nanostructured systems with efficiencies beyond the Shockley-Queisser limit of 32%. The challenge of realizing this vision is considerable and will require substantial advances in understanding material effects (e.g., architecture, interface, composition) and physical processes affecting the performance and stability of the devices.

By 2015, it is expected that companies will attain 10%-efficient modules that approach the criteria for solar module certification for thermal aging at 85°C for 1000 h in the dark and for light-soaking in full sunlight for 1000 h at 60°C. A realistic goal is that 20%-efficient laboratory-sensitized solar cells will be achieved. To reach these and more ambitious targets, it will be essential to further advance the fundamental (basic) understanding of the key factors that govern cell performance and stability and to set up the technological foundation for packaging and interconnecting the sensitized solar cells suitable for residential and commercial applications and integration within building materials.

Metrics

Parameter	Present Status (2007)	Future Goal (2015)
Champion device efficiency	11%	16%
Laboratory cell degradation	<5% after stress at 80°C for 1000 h in dark or after light-soaking for 100 h @ 1 sun at 60°C	<5% after stress at 85°C for 3000 h in the dark or after light-soaking for 3000 h @ 1 sun at 60°C
Module efficiency	5%–7%	10%
Outdoor module degradation	<15% in 4 yrs	<15% in 10 yrs
Identification of key degradation mechanisms	Degradation mechanisms are controversial	Primary degradation mechanisms identified

Identified Needs

			Nat'l Lab			Industry		
Need	Significance	University	NREL	Sandia	Other	TPP	Incubator	Other
Conduct fundamental research relating material effects with their impact on device physics/chemical processes to the solar cell efficiency and stability. Identify the most-promising cell materials and configurations (e.g., quantum dot, molecular dye, or inorganic sensitizers; conducting phase; and nanostructured architecture) for highest device efficiency and durability.	Understanding the fundamentals is the most-efficient pathway to realizing the real potential of this technology.	X	X					
Develop next-generation sensitizers, nanostructured architectures, and charge-conducting phases.	Improve efficiency and stability.	X	X					
Investigate materials for sealing cells containing liquid, quasi-solid, or solid conducting phases.	Improve cell stability.	X	X	X	X	X	X	X

Investigate inexpensive conducting glass or alternate materials (e.g., flexible foils) that serve the same function.	Lower the cost of the conducting substrate for specific applications (e.g., power windows, roofs, portability).	x	x	x	x	x	x	x
Investigate the issues of scaling up to mass production (e.g., screen-printing, spraying, roll-to-roll).	Develop inexpensive processing schemes.	x	x	x	x	x	x	x
Conduct indoor or outdoor tests of module efficiency and reliability contingent on the specific application.	Determine efficiency and reliability to provide feedback to further improve the technology.		x	x				
Conduct system analysis to understand requirements of applications (e.g., electricity-generating/conserving windows and other building-integrated PV components).	Understand the requirement and cost of systems for applications.	x	x	x	x	x	x	x
Engineer the product systems (e.g., cells must be linked together with the required interconnects to form modules).	Design system for scaled-up devices with acceptable efficiencies and stability.	x	x	x	x	x	x	x