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Solar Energy Technologies Program

National Solar Technology Roadmap:

Organic PV

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Management Report
NREL/MP-520-41738
June 2007

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National Solar Technology Roadmap: Organic PV

Scope

This roadmap addresses all forms of solar cells that use organic molecules—including polymers, dendrimers, small molecules, and dyes—as absorbers or transporters, either in fully organic devices or in devices that also contain inorganic nanostructures.

Technology development stage: Research-scale and small-area devices demonstrated at universities and start-up companies.

Target applications: At first, applications that can tolerate relatively low efficiencies and short lifetimes in return for very low cost. Later, the efficiencies and lifetimes should increase.

Background

Excitonic solar cells, which rely on exciton dissociation at a donor-acceptor interface to create carriers, have recently reached certified solar efficiencies of 5%. Improvements in material quality, device design, and understanding of the device physics have resulted in these increased efficiencies. Organic photovoltaics (OPV) follows on the heels of the commercial success of organic light-emitting diodes (OLEDs). Organic semiconductors are attractive because of the inherent low materials cost and low-energy, high-throughput processing technologies, and because of the huge variety of possible organic systems. The highest-certified OPV efficiencies so far come from polymer-fullerene blend devices. Other designs have been demonstrated or envisioned, including evaporated small-molecule devices, polymer-polymer blends, dendrimer-fullerene blends, and hybrid nanocrystalline oxide-polymer composites. Including the unique properties of inorganic nanostructures such as nanofibers, nanotubes, nanoparticles, or quantum dots into OPV devices, while retaining their low-cost fabrication, is a promising new area of research.

Roadmap Overview

The promise of organic photovoltaics is an ultra-low-cost technology that could be fabricated in a continuous process and implemented on flexible substrates. Its manufacture may be similar to, but inherently simpler than, conventional color-film production. The challenge of OPV is to increase the efficiency and reliability. Currently, cells have been demonstrated with a certified efficiency of ~5%; when encapsulated in glass, the degradation rate can be lowered to less than 5% per 1000 hours of exposure. The limitations to the efficiency are generally understood (e.g., the optical bandgap is too high; the band offset between donor and acceptor is not optimized; charge transfer, transport, and recombination are not optimized), but a rigorous fundamental understanding of these issues has not been obtained and is hindering progress in the field. Issues related to device degradation, such as photo-oxidation, interfacial instability and delamination, interdiffusion, and morphology changes are even more poorly understood. Although progress has been made using trial-and-error approaches to material and device development, the key to more rapid success of OPV technology is to better understand the fundamental requirements for high performance. Ultimately, the design across the entire hierarchy of components—from molecules to devices to modules—must meet the constraints required for efficient, stable operation in an integrated way. And it must be implemented in a manner that retains the low cost that is OPV's primary advantage. Development of more complex device designs, such as multijunction devices or inclusion of more exotic third-generation mechanisms into the OPV design, may be necessary to push efficiencies to competitive levels or to enable substantially higher efficiencies in the long term. The long-range goal of OPV is large-scale power generation, but the potential for low-cost and flexible form-factors may enable other applications in the short term.

Metrics

Parameter	Present Status (2007)	Future Goal (2020)
Champion device efficiency	5.2%	12%
Cell degradation	< 5% per 1000 h, research-scale	< 2% per 1000 h, module
Material figure-of-merit efficiency. Identification of candidate materials whose fundamental properties, such as optical absorption, band structure, and carrier mobility, allow for high theoretically attainable efficiencies.	Some material sets with improved figure-of-merit efficiencies exist.	Identification and synthesis of multiple donor-acceptor materials that meet all the fundamental requirements to achieve the Shockley-Queisser limit.

Identified Needs

			Nat'l Lab			Industry		
Need	Significance	University	NREL	Sandia	Other	TPP	Incubator	Other
Fundamental understanding/device physics—excitons, charge transport, recombination, band structure, and interfaces.	Place constraints on what fundamental properties are required and what performance goals may be achieved.	x	x					
Interfacial adhesion and electrical coherence of interfaces. Somewhat analogous to the lattice-mismatch problem in multilayers of inorganic solar cells.	These properties strongly influence both efficiency and stability.	x	x					x
Discovery of new donor and acceptor materials with optimized light absorption, band structure, and transport	Develop/identify molecules and materials that implement the fundamental concepts to enable high	x	x				x	

properties.	efficiency.							
Control of donor-acceptor morphology and new ideas for active-layer geometry.	Find optimized morphologies in which to arrange the donor and acceptor materials.	x	x				x	
Optimization of complete device architecture, including active layer, buffer layers, and electrode and transparent conducting oxide materials.	Develop a complete device geometry that harnesses the power captured in the active layer.	x	x				x	
High-throughput fabrication techniques for scale-up to larger-area devices and atmospheric processing.	Develop large-area, high-speed fabrication techniques that retain the efficiency of laboratory-scale cells.		x			x	x	
Studies of reliability and long-term degradation mechanisms.	Identify degradation pathways and use to improve molecule and device design.	x	x				x	
Incorporation of third-generation mechanisms theoretically capable of exceeding the Shockley-Queisser limit.	May be required for short-term development; desirable or necessary for long-term.	x	x					