Crystalline-Silicon Solar Cell Development Sponsored by the US Department of Energy

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The US Department of Energy (DOE) supports crystalline-silicon (c-Si) photovoltaic (PV) technology primarily through two of its National Laboratories: Sandia National Laboratories and the National Renewable Energy Laboratory (NREL). At Sandia, the c-Si effort is conducted by the Cell Development team, led by James Gee, part of the PV System Components Project, managed by Paul Basore. At NREL, the c-Si effort is conducted by the Crystalline Silicon team, led by Ted Ciszek, part of the Crystalline Silicon and Advanced Devices Project, managed by John Benner. The program at both labs is heavily oriented toward close collaboration with the PV manufacturing industry in the United States. Both labs also support university research tied to industry requirements.

Sandia and NREL share responsibility for supporting crystalline-silicon technology, which includes multicrystalline and monocrystalline flat-plate technologies and concentrator technology. Sandia's activities are oriented toward device and module engineering. NREL's activities are oriented toward materials growth and analysis. Both labs address processing issues, Sandia from the perspective of device performance, and NREL from the perspective of material performance.

Activities planned for the current fiscal year at Sandia include investigation of specific industrial cell processing issues using Sandia's Photovoltaic Device Processing Laboratory (PDFL), as well as several processing issues of general interest to companies using multicrystalline silicon. A significant and difficult goal for Sandia this year will be the fabrication of a 15%-efficient prototype module using large-area multicrystalline cells. Sandia also provides primary funding for the University Center of Excellence in Photovoltaic Research and Education at the Georgia Institute of Technology.

NREL's plans for c-Si this fiscal year include continuation of the University Silicon Materials Research Program, which funds research at six universities to study the effect of cell processing on the properties of silicon materials. As the lead DOE laboratory for thin-film technologies, NREL supports the development of thin-film silicon cells by providing both funding and expertise. NREL also provides substantial funding to the PV industry through the PV Manufacturing Technology (PVMat) initiative, some of which supports the development of c-Si cell technology either directly or indirectly.

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Crystalline-Silicon Activities at Sandia and NREL

Sandia assumed the lead role for DOE c-Si technology upon completion of the Flat-Plate Solar Array project at the Jet Propulsion Lab in 1986.

- Sandia and NREL programs in c-Si are heavily oriented toward close collaboration with the PV manufacturing industry in the United States: Monocrystalline Czochralski and float-zone materials, Multicrystalline cast-ingot, sheet, and ribbon materials.
- Sandia's activities are oriented toward device and module engineering.
- NREL's activities are oriented toward materials growth and analysis.
- Both labs address processing issues, from their different perspectives.
- Both labs support university research tied to industry requirements.

Major Elements of DOE Support for c-Si Technology

Sandia Lead Role:

- Photovoltaic Device Fabrication Laboratory (\$1M)
- Silicon Cell and Module Performance Testing (\$1M)
- Center of Excellence in Photovoltaic Research and Education (\$0.5M)
- Multicrystalline Silicon Research Cooperative (\$0.5M)
- Development of Line-Focus Concentrating Collectors (\$0.5M)

NREL Lead Role:

- Photovoltaic Manufacturing Technology Initiative (\$8M related to c-Si)
- Silicon Materials Research Program (\$1.5M)
- Thin-Film Silicon (\$1M)
- Module Reliability and Development of Qualification Tests (\$1M)

Sandia c-Si Cell Development Activities for FY 1994:

- **Photovoltaic Device Fabrication Laboratory (PDFL)**
 - Siemens Solar: Increase performance of thin cells.
 - AstroPower: Improve blue response of Silicon-Film cells.
 - Crystal Systems: Demonstrate cell results from reusable crucible.
 - Texas Instruments: Improve blue response of Spherical cells.
- **Multicrystalline Silicon Research Cooperative (MSRC)**
 - Solarex, Crystal Systems, AstroPower, Texas Instruments, (Mobil Solar)*
 - Demonstration of 16%-efficient large-area multicrystalline cells
 - Demonstration of 15%-efficient multicrystalline module
 - Phosphorus and aluminum impurity-gettering processes
 - Hydrogen defect passivation (NREL)
 - High-intensity optical processing (NREL)
 - Low-temperature surface passivation
- **Univ. Center of Excellence in Photovoltaic Research and Education**
 - Georgia Institute of Technology*
 - Silicon cell fabrication available to researchers at other US colleges.
 - Process development for industrial materials.
 - Fundamental studies of photovoltaic device physics.

NREL c-Si Cell Development Activities for FY 1994:

- **University Silicon Materials Research Program**
 - Duke University: Influence of self-interstitial injection on defects.
 - Georgia Tech: Post-growth quality enhancement techniques.
 - Berkeley: Identification and control of lifetime-reducing defects.
 - MIT: Role of defects and impurities in processing and performance.
 - Univ. of South Florida: Optimization of gettering processes.
 - North Carolina Univ.: Electrical and structural characterization.
- **Thin-Film Crystalline Silicon Development**
 - AstroPower: Deposition and growth on a coated ceramic substrate.
 - SUNY/Buffalo: Deposition of thin silicon films.
 - NREL: Growth of films from copper solutions.
- **Photovoltaic Manufacturing Technology Initiative (PVMaT)**
 - Contracts that directly or indirectly support c-Si cell development:*
 - AstroPower, Entech, (Mobil Solar), Siemens Solar, Solarex, Spire, Texas Instruments
- **Cooperative Research and Development Agreements:**
 - AstroPower: Silicon crystal growth dynamics
 - Texas Instruments: Upgrading metallurgical-grade silicon

Opinions of the DOE Photovoltaic Program that Impact Support for Crystalline Silicon Technology

The following assessments and predictions are not universally accepted within the DOE program, but they are currently the prevailing opinion:

- Today, the primary impediment to growth in the market for photovoltaic systems is the reliability and standardization of balance-of-system components, not the price or availability of modules.
- The price of durable modules based on crystalline silicon will not drop below \$2/watt in the foreseeable future, a price too high to significantly impact electric utility generation in the United States.
- Thin-film modules will eventually displace crystalline silicon for power applications, perhaps as early as the year 2000.
- Commercial companies that benefit from services provided by the national laboratories should pay a portion of the cost of those services, to ensure that the government's resources are applied where the demand is greatest. The amount of industrial cost sharing should depend on the maturity of that sector of the PV industry.