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U.S. Amorphous Silicon Research Project

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NOTICE

U.S. AMORPHOUS SILICON RESEARCH PROJECT

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Abstract

The U.S. Department of Energy (DOE) established the Amorphous Silicon Research Project (ASRP) in 1983 at the Solar Energy Research Institute (SERI). The ASRP was given the responsibility for developing an Amorphous Silicon Research Plan. A summary of this research plan is presented.

Introduction

The United States National Energy Policy Plan calls for a stable supply of energy at reasonable prices using a balanced mix of conventional and renewable energy resources. Photovoltaic conversion of sunlight to electric power can help to achieve this goal—provided that the relatively high cost associated with this technology at present can be reduced. The cost-competitiveness of promising new energy sources such as photovoltaics is of primary importance to their eventual deployment in the energy mix of the future. A serious effort is being carried out in this country to develop thin-film amorphous silicon technology, a leading candidate for cost-effective photovoltaic power applications. Progress to date in research, development, and now commercialization of amorphous silicon photovoltaics has surprised even its strongest proponents. To continue progress in amorphous silicon research and development, the photovoltaic energy technology division of the U.S. Department of Energy (DOE) established in 1983 the Amorphous Silicon Research Project (ASRP) at the Solar Energy Research Institute (SERI). The ASRP office was given the responsibility for developing and implementing an Amorphous Silicon Research Plan. This plan addresses amorphous silicon thin-film research and development for five years (FY 1984 through FY 1988).

Purpose

In accordance with DOE mandates and policy guidance of the National Photovoltaics Program, the Amorphous Silicon Research Project sponsors research and development in amorphous silicon photovoltaics technology that will result in a technology base from which private enterprise can choose options for further development and competitive application in electrical energy markets in the U.S. and abroad.

Planning Target

For photovoltaics to become a viable energy supply option, photovoltaic-generated electricity, either in distributed form or in central-station configurations, must demonstrate economic and performance parity with electricity from competing conventional alternatives. To guide federal/industry partnerships toward this parity, mutually developed long-term (late 1990s) technical goals have been established. These cost and efficiency goals for flat-plate technology are presented in Table 1.

Table 1. Federal/Industry Long-Term (Late 1990s) Technical Goals (1982 dollars)

	Flat-Plate Systems
Module efficiency*	13% - 17%
Module cost	$40 - $75/m^2
Balance-of-system cost —Area-related —Power-related	 $50/m^2 $150/kW
System life expectancy	30 years

*Measured at 28°C and AM1.5.

Ultimately, however, the final achievement and demonstration of these goals are the responsibilities of private industry. The Federal Government will provide assistance by developing component and process technology that will help to achieve the efficiency and durability goals and by validating the system and component costs goals. Industry must provide further development and scale-up to achieve the technical cost goals.

These goals have evolved as a result of several studies performed by government and industry. The most recent study, sponsored by the electric utility industry, suggests that photovoltaic-generated electricity produced at a 30-year levelized cost of 15¢ per kilowatt-hour would represent a viable energy supply alternative for the nation. While national and state energy policies can affect the validity of the target cost in specific regions, this levelized cost of 15¢ per kilowatt-hour appears to be a reasonable long-term planning target. The technical goals listed in Table 1 are based on this target.

Figure 1 reflects the results of calculations that lead to the planning target and the technical goals. They are based on a 12.5% discount rate and an 8.5% inflation rate. The 15¢ per kilowatt-hour target is stated in levelized current-year dollars, which is equivalent to 6.5¢ per kilowatt-hour in constant 1982 dollars. The Department of Energy's National Photovoltaics Program Five-year Research Plan presents a more detailed explanation of these assumptions and calculations.

Technical Plan

The ASRP project is organized into two primary and five secondary research activities (see Table 2). The two primary research activities address (1) single-junction solar cells, and (2) multijunction, stacked solar cells. The five secondary research activities focus on (1) material deposition rate; (2) alternative material deposition methods, such as chemical vapor deposition (CVD); (3) light-induced effects; (4) device testing and reliability; and (5) supporting research, such as theory, plasma kinetics, and transparent conductors. The two primary research activities involve strong government/industry partnerships made up of multidisciplinary teams whose objective is to achieve

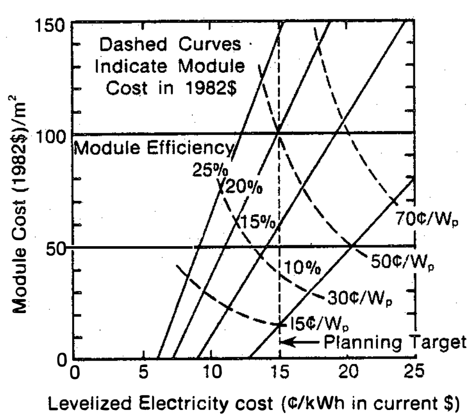

Figure 1. Module Cost and Efficiencies vs. 30-Year Levelized Electricity Costs for Flat-Plate Photovoltaic Systems ($50/m^2 area-related balance-of-system costs)

Table 2. Amorphous Silicon Research Project Activities

Primary Activities

- Single-junction solar cells
- Multijunction, stacked solar cells

Secondary Activities

- Material deposition rate
- Alternative deposition methods
- Light-induced effects
- Device testing and reliability
- Supporting research: theory, plasma kinetics, etc.

improved photovoltaic device efficiencies. Such multidisciplinary research is required because the various parts of thin-film photovoltaic devices are strongly interdependent and cannot be pursued effectively in isolated projects. This is a consequence of the thin-film nature of the technology, whereby surfaces/interfaces play a major role in the properties of the device. Research in single-junction solar cells will lead to meeting the near-term DOE goals for thin-film photovoltaic modules and will also provide the basis for the longer-term development of multijunction, stacked solar cells. These multijunction devices are needed to meet the longer-term efficiency goals, above 20%, of the DOE program. The five secondary activities relate to specific tasks in support of the two primary activities and provide a mechanism for investigating newer options. Research conducted in the two primary activities is organized under the following five major categories, concentrating, in the near term, on the first three:

- Materials Research
- Cell R&D
- Submodule R&D
- Process Development
- Module R&D.

A. Single-Junction Solar Cells

The objectives of this activity are to improve the understanding and efficiency of single-junction amorphous silicon solar cells and to bring the U.S. technology base to a position where U.S. industry can remain competitive in the international arena. This is to be accomplished by strong government/industry partnerships, including federal program support for at least three multidisciplinary industrial teams to improve the conversion efficiency of single-junction solar cells, address stability and reliability questions, and perform the research required for making proof-of-concept, intraconnected, single-junction solar cells (submodules). University and DOE research center research projects will be supported by the federal program to augment industrial contract efforts. The multidisciplinary teams will be selected by competition from the private sector; multi-year contracts will be awarded, pending availability of funds, to achieve time-phased goals. The success of the research program and the essential deployment of the technology by industry will be enhanced by (1) requiring a serious commitment from the participating organizations, as evidenced by substantial cost-sharing (at least 30%) of the total program costs; and (2) strengthening the supporting government research program, which addresses specific technical problems and newer, high-risk options that the private sector cannot reasonably be expected to undertake.

B. Multijunction Solar Cells

Theoretical calculations show that single-junction amorphous silicon solar cells using today's amorphous materials have a theoretical conversion efficiency limit of 18%-20%. The practically achievable conversion efficiency of single-junction solar cells is estimated to be 13%-15%. The federal long-term technical goal for flat-plate photovoltaic systems is a module efficiency/cost combination of 13% at $40/m^2$ to 17% at $75/m^2$. To increase the probability of meeting the long-term technical goals, solar cell devices such as stacked cells, which consist of two or three single-junction solar cells in a vertical stack, offer potentially much higher conversion efficiencies. The theoretical limit of the multijunction stacked solar cell is almost 30%. However, several effects reduce this theoretical limit to a practical limiting efficiency of 20%-25%. In addition to the higher efficiencies possible with stacked cells, these devices may be inherently more stable than a single-junction, "thick" p-i-n cell because of the thinner layers of active, or intrinsic, material in each of the individual p-i-n cells that make up the stacked device. Stacked-cell efficiencies are currently limited by the quality of the alloy material, which in turn limits the current from devices utilizing this material.

The objective of the research activity in this area is to perform research both in specific areas of amorphous silicon alloy materials and deposition techniques, and in the structure of stacked cells, to achieve solar cell efficiencies of greater than 20% in the long term. This will be accomplished by government/industry/university cooperative efforts that include federal program support for a least two multidisciplinary teams with multiyear contract awards, pending availability of funds, having time-phased research goals. Cost-sharing of at least 20% is required to enhance the probability of success and to achieve an effective technology transfer to the private sector. This project will be supported by the secondary research activities. High-efficiency, multijunction solar devices offer conversion efficiencies potentially above 20% in the long term. However, it must be recognized that some significant research successes are required to achieve the technical goals; thus, this activity involves greater risk than the single-junction, but lower efficiency, approach.

Project Organization

The ASRP is directed by the Project Office Manager at SERI. The manager provides the centralized leadership necessary to ensure that the project is implemented in conformance with national policy, priorities, and directives. Management of specific technical activities is decentralized so that the special expertise of all federal research centers involved can be utilized.

Schedule and Decision Points

In order to provide management with guidance in evaluating the progress and direction of research tasks, technical milestones and project assessment points (depicted in Figure 2) have been established. The milestones are used as targets by the ASRP and research groups for allocation of resources and evaluation of technical achievement over periods of time. Though the milestones are subject to annual reevaluation in terms of progress and budget considerations, their achievement through appropriate planning and resource allocation is an important responsibility of the research groups.

Present Program

The current research and development subcontracts program managed by SERI includes 16 subcontractors: seven with industry, seven with universities, and two government laboratories. Research is also being conducted on site at the DOE research centers (SERI and Jet Propulsion Laboratory). Federal budget allocations for the amorphous program for fiscal year 1984 (October 1, 1983 - September 30, 1984) totaled $8.7 million.

The U.S. Amorphous Silicon Research Plan calls for advancing the state-of-the-art by way of multiyear subcontracts based on government/industry/university cooperative efforts. Implementation of the plan began early in 1983 when multiyear, competitive procurements were issued in single-junction cells/submodules and multijunction cells. The objective of the single-junction initiative is to improve the understanding and the efficiency of cells/submodules using single-junction p-i-n solar cells based on material grown by the glow discharge deposition method. The objectives of the multijunction initiative are to research amorphous silicon alloy materials and the structure of stacked cells. The research is directed toward establishing a base of knowledge that will help achieve longer-term efficiencies of 20% or more.

The competitive procurement process was completed on February 1, 1984, when the final subcontract was signed. Subcontracts were awarded to four research teams: Chronar Corporation, 3M Corporation, Solarex Corporation, and Spire Corporation. Figure 3 shows the general technical approaches taken by each company to achieve the program goals. Amorphous materials will be deposited using the glow discharge deposition method. DC or RF excitation with two or three electrodes will be used to generate the plasma.

The total program cost over the three-year life of the subcontracts is $18.6 million, with approximately

Project Milestone ▲
Project Decision Point △

Activity	1984 FY84	1985 FY85	1986 FY86	1987 FY87	1988 FY88
Single-Junction Solar Cells					
1. Materials Research					
Deposition Method			▲ (Select)		
Stability (light-induced)			△ (Assess)		
Deposition Rate				▲ (Select Method)	
2. Cell R & D					
Achieve Efficiency with Deposition Rate Goals			▲ 12% (1 cm^2)	▲ 10% (1 cm^2)(20 A/s)	▲ 13% (1 cm^2)
3. Submodule R & D					
Achieve Efficiency and Size Goals	▲ 6% (50 cm^2)	▲ 7% (100 cm^2)	▲ 8% (1000 cm^2)		▲ 12% (100 cm^2)
4. Process Dev. & Module R&D					
Multichamber Deposition System	▲ (Design)	▲ (Operational)	△ (Assess)		
Achieve Efficiency and Size Goals			△ (Assess R & D)		▲ 9% (10,000 cm^2)*
Multijunction Solar Cells					
1. Materials Research					
Preparation and Evaluation	▲ (Initiate E_g<1.5 eV)	▲ (Initiate E_g>1.7 eV)		▲ (Assess/Select)	
Deposition Method				▲ Select	
Stability (light-induced)				△ (Assess)	
Deposition Rate				△ (Assess)	
2. Cell R & D					
Achieve Efficiency Goals		▲ 12% (1 cm^2)			▲ 18% (1cm^2)
Research Multichamber Deposition System	▲ (Design)	▲ (Operational)		△ (Assess)	
3. Submodule R & D					
Achieve Efficiency and Size Goals					▲ 13% (100 cm^2)
4. Process Dev. & Module R&D					
Deposition System				△ (Evaluate)	
Achieve Efficiency and Size Goals				△ (Assess R & D)	

*Efficiency and size milestones for module require substantial industry participation
Note: Efficiencies are measured at 28° C and AM 1.5

Figure 2. Amorphous Silicon Research Project Schedule and Decision Points

70% of the total cost contributed by the government and about 30% contributed by the subcontractors. Some subcontractors are now developing a multichamber deposition system to fabricate the solar cells entirely on company funds, and the cost of this work is not included in the values presented here. Goals of the program are to demonstrate stable p-i-n solar cells of at least 12% (AM1) efficiency with areas of at least 1 cm^2, a stable submodule of at least 8% (AM1) efficiency having a total area of at least 1000 cm^2, and proof-of-concept multijunction amorphous silicon alloy thin-film solar cells that will lead to achieving an 18% efficiency goal in 1988.

In addition to the multiyear, multidisciplinary activities outlined above, the federal program under the ASRP is supporting research in the basic properties of hydrogenated amorphous silicon and amorphous silicon alloy materials, light-induced effects, high deposition rates, theory, and alternative deposition options. These programs will be discussed in a future article.

Outcome

The five-year Amorphous Silicon Research Plan presents a realistic approach to establishing thin-film amorphous silicon as a viable option for future commercialization. The plan is designed to maintain progress in a near-term technology—single-junction thin films—while continuing to develop the high-efficiency, long-term options of multijunction concepts. It outlines the pathway for successfully competing with other energy options—for example, oil, gas, coal and nuclear energy—for generating substantial amounts of electrical energy.

The plan, in summary, addresses amorphous silicon thin-film research and development for the next five years (FY 1984 through FY 1988). The program plan consists of two primary research activities: single-junction thin films and multijunction concepts. The two research activities activities are further divided

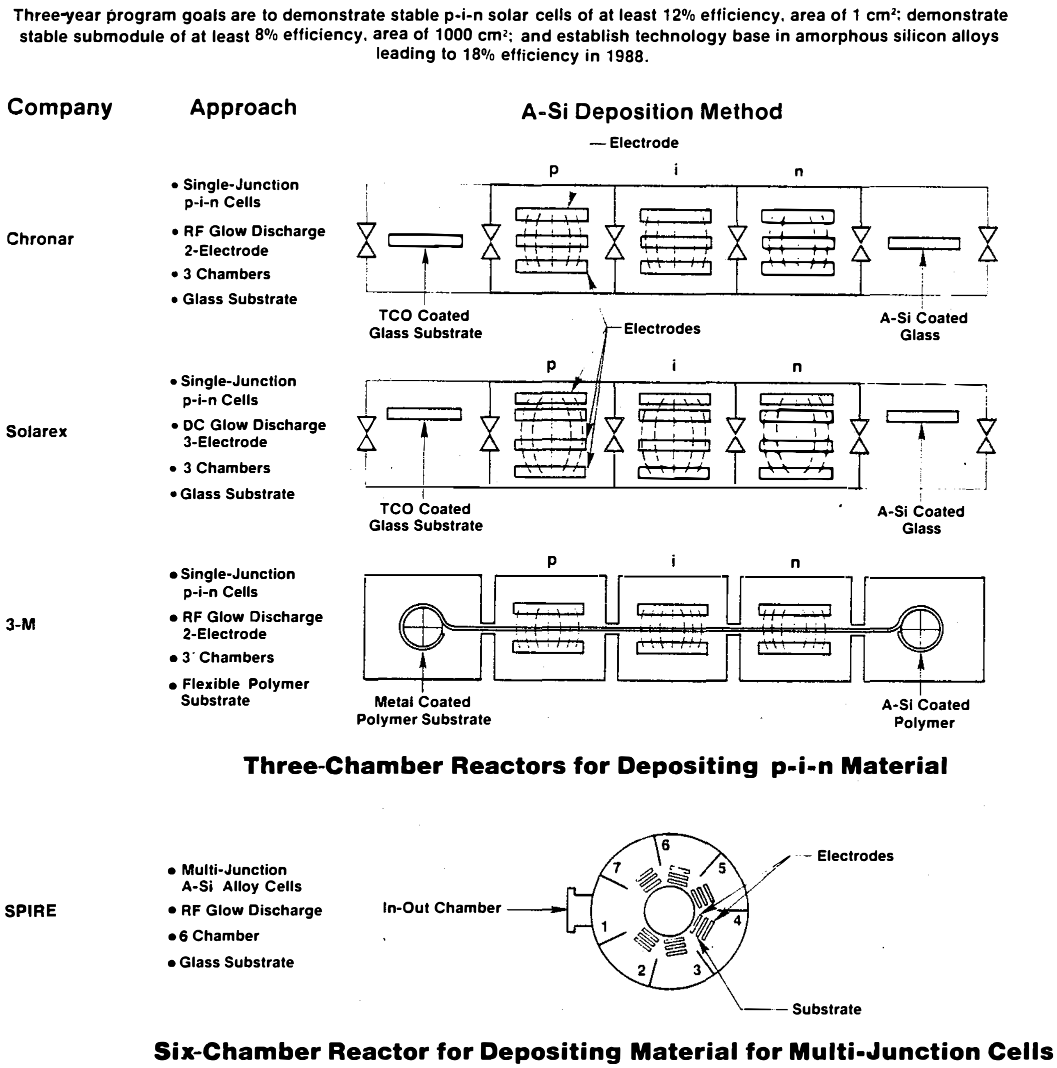

Figure 3. Generic Representations of Technical Approaches of Multiyear Initiatives in Amorphous Silicon

into five R&D categories: Material Research, Cell R&D, Submodule R&D, Process Development, and Module R&D. During the ensuing five years, Materials Research, Cell R&D, and submodule R&D will constitute the major effort, and the other two categories will receive increasing attention with time.

The research performed during this five-year period is expected to increase solar cell efficiency, reduce the number of deposition options, finalize the cell structure(s), solve the light-induced degradation problem, increase the deposition rate, expand the data base on amorphous silicon alloy materials, and provide data for expansion into large-area module research.

This plan is time-phased along technology stages and, at the same time, it provides for a continuing government/industry partnership for direct technology transfer. Government/industry commitment to and confidence in amorphous silicon photovoltaic technology as a viable energy option are the most critical factors in the overall success of the project.