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RESEARCH PROGRESS IN THE DOE/SERI AMORPHOUS SILICON RESEARCH PROJECT

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ABSTRACT

The Amorphous Silicon Research Project (ASRP), established at the Solar Energy Research Institute (SERI) in 1983, is responsible for all U.S. DOE government-supported research activities in the field of amorphous silicon photovoltaics. The objectives and research directions of the project have been established by a Five-Year Research Plan developed at SERI in cooperation with the Department of Energy in 1984. In order to accomplish project goals, research is performed by a combination of i) multi-year programs consisting of multi-disciplinary research teams based on strong government/industry partnerships and ii) basic research performed in university, government, and industrial laboratories. A summary of recent research progress in the ASRP program is presented.

INTRODUCTION

The ASRP project is organized into two primary and five secondary research activities. The two primary activities are divided into research on high-efficiency single-junction and high-efficiency multi-junction stacked solar cells. A key feature of the primary activities is that single-junction solar cell research directly provides the technology base and expertise necessary for the development of multi-junction stacked cells, which are expected to achieve the longer term, high-effiency goals of 20% and above called for in the DOE National Photovoltaics Program. The major goals for the applied research program are outlined in the Five-Year Research Plan for the Amorphous Silicon Research Project [1] and are summarized in Table 1.

Table 1. Primary Long-Term Goals of the Amorphous Silicon Research Project

	FY 86	FY 88
Single-Junction Cell R&D	12% (1 cm^2)	13% (1 cm^2)
Single-Junction Submodule R&D	8% (1000 cm^2)	12% (100 cm^2)
Multi-Junction Cell R&D		18% (1 cm^2)

In order to achieve these goals a strong reliance is placed on government/industry partnerships established in 1984 having the following characteristics: i) research is performed under multi-year subcontracts in which progress toward aggressive long-term objectives is measured on the achievement of significant milestones, ii) research is performed by highly interacting multidisciplinary teams capable of addressing all aspects of difficult projects, and iii) significant cost sharing (a minimum of 30%) is required to leverage limited resources and allow the protection of proprietary industrial information.

Critical basic research is performed under the five secondary activities in order to address key fundamental issues, support the achievement of long-range basic research objectives, and provide a mechanism for investigating newer options. The five activities relate to i) light-induced effects; ii) material deposition rate; iii) alternate deposition methods; iv) device testing and reliability; and v) supporting research, including theory, plasma kinetics, and alloy materials.

MULTI-YEAR PROGRAMS

Four multi-year subcontracts, each three years in duration,were awarded during the first half of FY 1984 establishing research teams at Chronar Corporation, 3M Company, Solarex Thin Films Division, and Spire Corporation. Valued at a total of 18.6 million dollars, of which 30% is cost shared by industry, these programs are directed toward the objective of understanding and improving the performance of amorphous silicon single-junction cells and submodules based on material grown by the plasma-assisted chemical vapor deposition (glow discharge) method, and the incorporation of amorphous silicon alloy materials into high-efficiency multi-junction, stacked solar cells. Chronar, 3M, and Solarex are performing single-junction research and Spire is performing multi-junction research under the present program structure. To improve the probability of success in achieving overall objectives, each organization is pursuing a technical option that draws upon the internal strengths and technical expertise previously existing within the company. An overview of these technical options is given in Figure 1.

Single-Junction Cell/Submodule Research

The primary goals of the single-junction three year programs are to demonstrate p-i-n solar cells of 12% efficiency and 1 cm^2 in area, and to demonstrate series interconnected submodules of 8% efficiency, 1000 cm^2 in area, by FY 1986. All efficiency goals have specific stability criteria associated with them. As shown in Figure 1, three technical approaches are being used in single-junction research [2,3]. Both Chronar and Solarex use tin oxide coated glass as the substrate and aluminum as a back metal contact. For deposition of amorphous silicon, Chronar uses two-electrode RF glow discharge and Solarex uses three-electrode DC glow discharge. 3M uses two-electrode RF glow discharge deposition to deposit films on metal-coated polyimide flexible polymer substrates and an ITO front contact material developed in-house. In order to minimize cross-contamination problems, multi-chamber deposition systems will be constructed in each program for cell and submodule research based on i) the consecutive reactor design employing horizontal electrodes developed at RCA (Solarex), ii) a reactor design using vertical electrodes (Chronar), and iii) a continuous roll-to-roll system design employing a polyimide web substrate (3M). Laser scribing technology is used to interconnect cells in submodules. In all three organizations the processing capability exists for all steps involved in complete submodule fabrication.

During Phase I of the single-junction program, all subcontractors were on track in meeting individual milestones. SERI has measured efficiencies of 7-8% on Chronar p-i-n cells up to 1 cm^2 in area and Chronar has recently reported cell efficiencies of 9-10% on 0.1-cm^2 cells. SERI has measured efficiencies between 8 and 9% on Solarex cells up to 1 cm^2, and Solarex has recently reported efficiencies of 9-10.5% on cells up to 1 cm^2. SERI has measured efficiencies for Chronar submodules of 5 to 5.5% over active areas up to 720 cm^2. For Solarex submodules SERI has measured efficiencies of 5-6% over active areas of 80 cm^2 and Solarex has recently reported efficiencies of 6-7%. 3M has proceeded in optimizing p-i-n cells on polyimide substrates and has reported efficiencies over 7% on small-area cells. In all organizations, complete diagnostic and measurements capabilities have been established. Submodule research is being performed on one-square-foot glass substrates at Chronar and Solarex.

Multi-Junction Cell Research

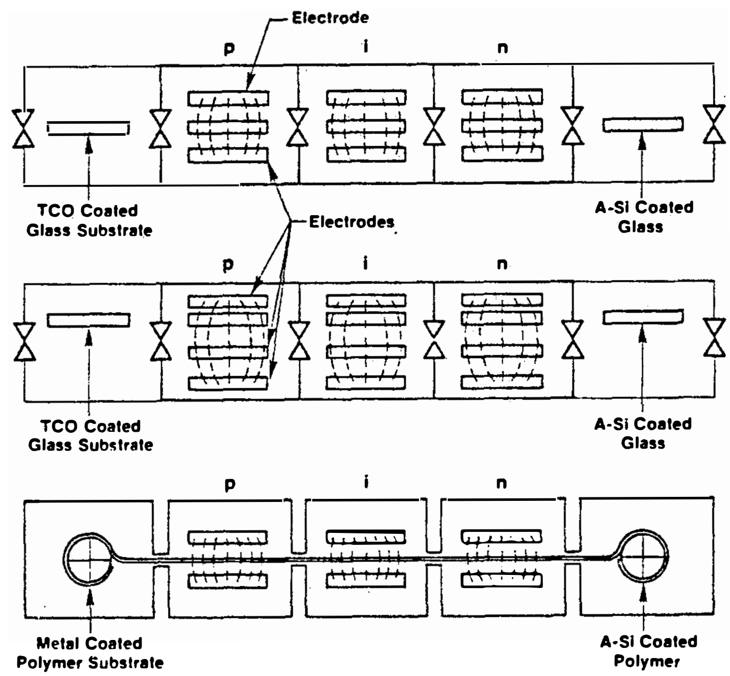
The long-term goal of the multi-junction program is to demonstrate an efficiency of 18% by FY 1988 for cells based on amorphous silicon alloy materials. In order to achieve this objective, Spire is performing research based on a realistic design for a multi-junction, tandem cell consisting of an a-Si:H top cell and an a-(Si,Ge):H bottom cell. The two-cell structure will be optimized for bandgaps of 1.7 and 1.45 eV to achieve practical conversion efficiencies in the range of 17-20% [4]. It is perceived

Technical Approaches of New Multi-Year Initiatives in Amorphous Silicon

Three year program goals are to demonstrate stable p-i-n solar cells of at least 12% efficiency, area of 1 cm^2; demonstrate stable submodule of at least 8% efficiency, area of 1000 cm^2; and establish technology base in amorphous silicon alloys leading to 18% efficiency in 1988.

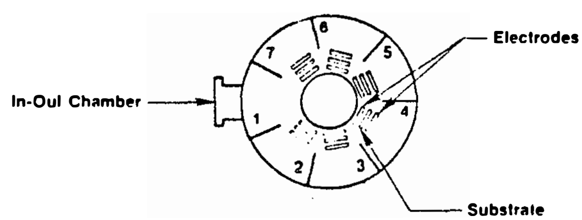
Company	Approach
Chronar	• Single-Junction p-i-n Cells • RF Glow Discharge 2-Electrode • 3 Chambers • Glass Substrate
Solarex	• Single-Junction p-i-n Cells • DC Glow Discharge 3-Electrode • 3 Chambers • Glass Substrate
3-M	• Single-Junction p-i-n Cells • RF Glow Discharge 2-Electrode • 3 Chambers • Flexible Polymer Substrate

A-Si Deposition Method



Three Chamber Reactors for Depositing p-i-n Material

Company	Approach
SPIRE	• Multi-Junction A-Si Alloy Cells • RF Glow Discharge • 6 Chamber • Glass Substrate



Six Chamber Reactor for Depositing Material for Multi-Junction Cells

Figure 1. Overview of the Technical Approaches Being Persued in the ASRP Project for Single-Junction and Multi-Junction Research

that this cell structure will have advantages in terms of stability as well.

During Phase I of the multi-junction program, Spire has concentrated on the construction of a six-sector reactor consisting of six consecutive RF glow discharge reaction chambers for preventing cross-contamination in the deposition of intrinsic and doped alloy material layers. To date, Spire has reported small-area single-junction a-Si:H cell efficiencies up to 7.8%, small-area single-junction a-(Si,Ge):H cell efficiencies up to 5.8%, and small-area a-Si:H/a-(Si, Ge):H tandem cell efficiencies up to 6.7%. The six-sector reactor is presently operational in a manual mode.

BASIC RESEARCH PROGRAM

In addition to the cell/submodule activities covered in the previous section, a large basic research program is being conducted in support of the achievement of long-range goals. These basic research activities are outlined in Figure 2 and have recently been extensively reviewed [5].

Light-induced effects are being studied at Xerox, MIT, and Oregon State University. The effect of light soaking in a-Si:H samples deposited in an ultra-high vacuum (UHV) system or a conventional deposition system has been studied by measuring the change in dangling bond density using electron spin resonance (ESR). Although UHV-deposited samples have one to two orders of magnitude lower impurity levels than conventional glow discharge samples, the light soaking effect is nearly identical. This evidence indicates that impurities play a minimum role in generating light-induced effects. Two models for light-induced degradation in amorphous silicon are being examined based on specific defect sites in amorphous materials leading to charge trapping. Both models are self-limiting in terms of long-term stability and predict primarily short-term effects. Capacitance profiling studies indicate that light-induced effects may be the result of competing fundamental processes, complicating the interpretation of experimental observations.

The glow discharge deposition of silane and higher order silanes at high deposition rates is being investigated at Brookhaven National Laboratory and Vactronics Corporation. Brookhaven has reported a 6.2% cell efficiency for an intrinsic amorphous silicon layer deposited at 17 Å/second and is investigating doped and intrinsic film properties at deposition rates of 20 Å/second using disilane diluted in He. Vactronics is correlating film properties with deposition rate using monosilane diluted in hydrogen and deposited at high power densities.

The potential of thermal and photo-chemical vapor deposition (CVD and photo-CVD) as alternate deposition methods is being evaluated at Harvard University, Chronar Corporation, and the Institute of Energy Conversion (IEC). Primary emphasis is being placed on photo-CVD due to its potential for producing high-quality amorphous silicon films and minimizing the material damage encountered in the use of high-energy plasmas. Using mercury sensitized photo-CVD of disilane, Chronar has reported the achievement of a 5.9% efficiency for an all photo-CVD cell. IEC has also recently initiated a study of mercury-sensitized photo-CVD films from disilane. Using atmospheric pressure chemical vapor deposition, Harvard has investigated amorphous silicon films deposited at rates up to 90 Å/second. The preparation of a-(Si,Ge):H films by photo-CVD will be studied at IEC under a recently awarded subcontract in the SERI New Ideas Program.

Device testing and reliability measurements activities are being pursued at SERI and JPL. A strong effort is now being pursued by SERI to standardize efficiency measurements in the amorphous silicon field in coordination with the photovoltaic community and various international standards committees. An Amorphous Silicon Measurements Task Force was recently established by SERI consisting of university/industry/government representatives, and a workshop was conducted in February 1985. As a result of this workshop, recommendations were issued, which are

Outline of Fundamental Studies and
Supporting Research Activities

Light-Induced Effects	
XEROX-PARC, R. Street	- Optical and electronic properties of amorphous silicon alloy materials
MIT, D. Adler	- Theory of light induced effects
Oregon State U., J.D. Cohen	- DLTS measurements
SERI, T. McMahon	- Controlled stability measurements of a-Si:H materials and devices
Material Deposition Rate	
Brookhaven, P. Vanier	- Efficient a-Si cells at high deposition rates
Vactronics, B. Wiesmann	- Investigation of properties of materials deposited at high deposition rates
Alternative Deposition Methods	
Harvard, R. Gordon	- CVD of a-Si:H; SnO_x:F, and diffusion barriers
Chronar, A. Delahoy	- Photo-CVD of higher order silanes
Institute of Energy Conversion, B. Baron	- Photo-CVD of disilane
Device Testing and Reliability	
SERI, R. Hulstrom, L. Kazmerski, and D. Deblasio	- Cell and submodule indoor and outdoor standard measurements, resource assessment
JPL, R. Ross	- Submodule reliability measurements
Supporting Research	
SERI, H. Mahan	- Amorphous silicon alloy studies (C,Ge, and Sn)
Harvard, W. Paul	- Glow discharge of a-Si,Ge:H:F alloys
North Carolina State U. G. Lucovsky	- Dual magnetron sputtering of a-Si:Ge:H alloys
Rockwell, R. Haak	- Electrochemical Photocapacitance of a-Si:H materials and devices
NBS, Univ. of Colorado, A. Gallagher	- Glow discharge silane plasma characterization
NRL, W. Carlos	- ESR and NMR studies
JPL, D. Bickler	- Glow discharge reactor studies

Figure 2. Breakdown of the Basic Research Activities of the Amorphous Silicon Research Project

currently under review, for indoor/outdoor cell and submodule measurement procedures. The reliability of amorphous silicon cells and submodules is under investigation at JPL in terms of encapsulation issues and long-term stability.

In support of multi-junction cell research, fundamental amorphous silicon alloy studies are being performed at North Carolina State University, Harvard University, Xerox, and SERI. Using dual magnetron sputter deposition, NCSU has been able to control preferential hydrogen attachment to Si and Ge in a-(Si,Ge):H films by employing independent Si and Ge hydrogen plasmas. Harvard has found that the electronic properties of a-(Si,Ge):H films are affected by structural modifications in the material as the Ge content increases, as well as by band structure changes. Harvard has also recently initiated a study of fluorinated a-(Si,Ge):H materials by glow discharge deposition. a-(Si,Sn):H has been investigated extensively at SERI with the conclusion that poor electronic properties are due intrinsically to Sn.

Other supporting research activities focus on the measurement of material optical and structural parameters. NMR, ESR, and Photoluminescence studies at the Naval Research Laboratory are directed toward probing the existence of molecular hydrogen in amorphous silicon and characterizing the spatial distribution of defect states in films. Xerox has also correlated defect state density with stress parameters in amorphous silicon. The technique of Electrochemical Photocapacitance Spectroscopy (EPS) is being used at Rockwell to correlate reversible changes in defect state densities with light-induced effects. Detailed plasma diagnostic studies at the University of Colorado have established the important contribution of surface catalized reactions to the gas phase chemistry in glow discharge plasmas. JPL is investigating the design and scale-up of glow discharge deposition systems.

CONCLUSION

The Amorphous Silicon Research Project at SERI is pursuing an aggressive R&D program incorporating highly interacting and multidisciplinary teams in government/industry partnerships supported by a strong basic research program in university/industry/government laboratories. It is expected that the present ASRP program will achieve 12% efficiencies for small-area cells by FY 1986. The next step in the evolutionary development of thin-film amorphous silicon technology will be the challenge associated with multi-junction devices that should achieve conversion efficiencies of 20% in the long term. Building on our present knowledge of single-junction cells and alloy materials, we march toward that goal.

ACKNOWLEDGEMENT

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