5230-9
Photcvoltaics Program
Technology Development and Applications
Load Center

DOE / JPL-1012-80
Distribution Category UC-63b

Photovoltaic Research and Development in Japan

Katsunori Shimada

February 15, 1983

Prepared for
U.S. Department of Energy
Through an Agreement with
National Aeronautics and Space Administration
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ABSTRACT

The status of the Japanese photovoltaic (PV) R&D activities has been surveyed through literature searches, private communications, and site visits in 1982. The results show that the Japanese photovoltaic technology is maturing rapidly, consistent with the steady government funding under the Sunshine Project. Two main thrusts of the Project are: (1) completion of the solar panel production pilot plants using cast ingot and sheet silicon materials, and (2) development of large area amorphous silicon solar cells with acceptable efficiency (10 to 12%). An experimental automated solar panel production plant rated at 500 kW/yr is currently under construction for the Sunshine Project for completion in March 1983. Efficiencies demonstrated by experimental large area amorphous silicon solar cells are approaching 8%. Small area (< 5 cm^2) amorphous silicon solar cells are, however, currently being mass produced and marketed by several companies at an equivalent annual rate of 2 MW/yr for consumer electronic applications. There is no evidence of an immediate move by the Japanese PV industry to enter extensively into the photovoltaic power market, domestic or otherwise. However, the photovoltaic technology itself could become ready for such an entry in the very near future, especially by making use of advanced process automation technologies.

PREFACE

This report describes the current status of the photovoltaic research and development activities in Japan which was surveyed mainly during the author's recent visit to Japan in conjunction with presenting an invited paper at the 3rd Photovoltaic Science and Engineering Conference, May 19-21, 1982, Kyoto, Japan.

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SECTION I

INTRODUCTION

Japanese early involvement in solar photovoltaic (PV) R&D dates back to the early 1960s when Matsushita Wireless Research Laboratory was investigating cadmium sulphide solar cells. Soon afterward, Sharp Corporation succeeded in the production of practical solar cell modules using silicon crystals, and in 1963 it installed a 242-W solar array for a lighthouse which was the world's largest solar array at that time. Solar cell development continued thereafter mainly for space applications in support of the Japanese Scientific Satellite Program, initiated in 1965. However, synergetic development at Sharp Corporation for space and terrestrial solar cells maintained the company's lead in marketing single crystal solar cell modules for maritime safety applications.

In 1974, the Sunshine Project, which is a "large-scale" national project for the development of alternative energy sources, was formulated under the Ministry of International Trade and Industry (MITI). This formulation was concurrent with the initiation of the U.S. Department of Energy (DOE) Photovoltaic Program, reflecting Japanese recognition of the need to develop alternative energy sources.

At that time a number of companies which had experience in semiconductor R&D joined with the Project to build the Japanese technology base in solar photovoltaics. Also, several universities became involved in basic research for advanced solar cell materials. The university research was bolstered a few years ago by supplementary funding, especially in amorphous silicon solar cell research. Currently, five universities and scores of companies are involved in solar cell R&D funded by the Sunshine Project, and the majority of organizations are also conducting amorphous silicon solar cell R&D.

It seems that the conventional silicon solar cell technology is still a few years behind that of the United States especially in the mass production technology; but the Japanese amorphous silicon technology, including production, currently dominates the world. Also, the most recent information on the construction of Japanese prototype production plants reveals the steady progress and determination of the Japanese Sunshine Project.

In this report, the Japanese photovoltaic R&D status is described in detail. The report is structured so that the Sunshine Project is described first, as it is the driving force for the Japanese photovoltaic R&D. The industry and university activities are described in subsequent paragraphs in relation to the Project.

SECTION II

SUNSHINE PROJECT

The Sunshine Project is a national large-scale technological development program which was initiated in July 1974 for the purpose of securing solutions to future energy problems in Japan. Its headquarters is in the Ministry of International Trade and Industry. The organizational relationship of MITI with the Japanese Cabinet is shown in Figure 2-1.

The Sunshine Project consists of six R&D areas: (1) Solar Energy, (2) Geothermal Energy, (3) Coal Conversion, (4) Hydrogen Energy, (5) Supporting Research and Management, and (6) International Cooperation. Key items being pursued by each area are shown in Table 2-1 and the photovoltaic part of the Sunshine Project is shown in items 2 and 3 of the Solar Energy area.

The recent history of the Sunshine Project funding for all R&D areas is shown in Table 2-2. The Solar Photovoltaic Program received 73% of the 1981 Solar Energy Program funds as shown in Table 2-3. The photovoltaic program's funding increased dramatically in 1981 despite the reduction in the overall solar energy funds in 1981. It should be pointed out that the funds provided by the Sunshine Project are expended for procurements including capital equipment. Labor cost, therefore, is largely derived from companies and research institutions themselves. For example, only a fraction of the overhead cost and employee benefits are charged to the Project; most of these costs are charged directly to the company's operational fund. In the case of government research laboratories, such as Electrotechnical Laboratory (ETL), the labor is directly paid by MITI, of which ETL is a subsidiary. Thus, the total available photovoltaic program research funds are estimated at approximately $60M for photovoltaics in 1982.

The photovoltaic program is divided into two major disciplines, (1) technology and (2) research. Programmatically the technology part of the program is managed by the New Energy Development Organization (NEDO). NEDO was established in 1980 under MITI with the assistance of the private sector to promote the development of energy technology for commercializing alternative energy production and for developing alternative energy sources. As shown in Figure 2-2, the largest fraction (44.3%) of the Sunshine funds are allocated to the Photovoltaic Panel Production Experiments, followed by the Advanced Material and Device R&D, which has 24.2% of the budget. The research part of the program which is pursued largely by universities and research institutions, is managed directly by the Sunshine Project Headquarters.

The technology program, which received $22.2M[1] of FY 82 Sunshine Project funds, is carried out by subtasks, as shown in Table 2-4, through contracts with 16 companies.

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[1]Based on a 230-yen-per-dollar exchange rate.

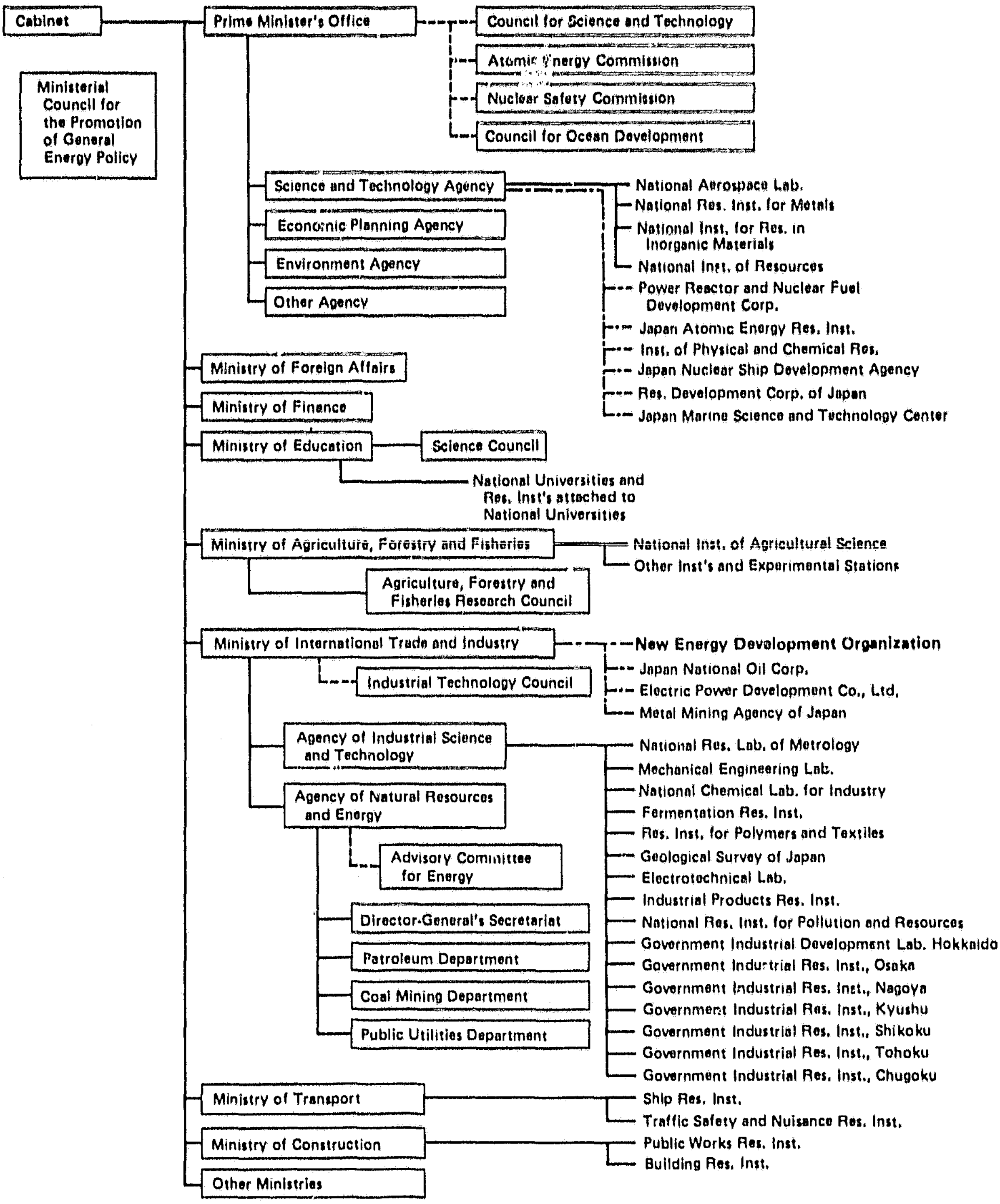

Figure 2-1. Japanese Government Structure

Table 2-1. Sunshine Project in FY 1981 (April 1981 - March 1982)[a]

Budget (million dollars)	Items
1. Solar energy (34.7)	(1) Test operation of solar thermal power electric plant (two 1,000-kW systems) (2) Development of photovoltaic power conversion system (3) Expansion of R&D on photovoltaic power generation (amorphous solar cell) (4) Development of solar systems for industrial process heat, etc.
2. Geothermal energy (40.1)	(1) Nation-wide geothermal resource survey (2) Field survey to test geothermal resource exploration technology (Sengan Kurikoma) (3) Environmental assessment of large scale power generator using deep geothermal reservoir ([illegible]ohi) (4) Development of the system to utilize hot water supply from deep seated reservoir (5) Development of power generation plant utilizing geothermal hot water
3. Coal conversion (58.8)	(1) Development of liquification plant (2) Development of high-calorific gasification plant (7000 m^3/day) (3) Development of low-calorific gasification plant (4) Expansion of basic research of liquification and gasification
4. Hydrogen energy (4.1)	Development of hydrogen manufacturing plant utilizing electrolysis
5. Supporting research and management (5.3)	(1) Expansion of research on ocean thermal energy conversion technology (2) Expansion of research on wind energy conversion system (Construction of wind energy conversion plant 100 kW)
6. International cooperation (2.9)	(1) USA-Japan joint research on geothermal energy utilization technologies (2) IEA countries-Japan multilateral cooperation
7. Other (0.5)	Office expenses, maintenance charge of research facilities, etc.
TOTAL: 146.4	

[a]Based on exchange rate of 230 yen per dollar.

Table 2-2. Sunshine Project Funding

Funding Area	FY, $M[a]		
	1980	1981	1974 - 1981
Solar Energy	41.5	34.7	122.8
Geothermal Energy	37.4	40.1	134.4
Coal Conversion	37.4	58.8	129.1
Hydrogen Energy	4.1	4.1	21.5
Other	4.1	8.7	26.2
Total	124.5	146.4	434.0

[a]230 yen-per-dollar exhange rate.

Table 2-3. Photovoltaic Program Funding

Funding Area	FY, $M[a]			
	1980	1981	1982	1983 (Request)
Photovoltaic Production and System Technology	5.7	18.7	22.2	
Amorphous Silicon R&D	2.0	5.7	7.0	9.4[b]
Other Material R&D	4.2	0.9		
Total	11.9	25.3	29.2	9.4

[a]230 yen-per-dollar exhange rate. [b]Nikkei Electronics, Japan, Dec. 1982.

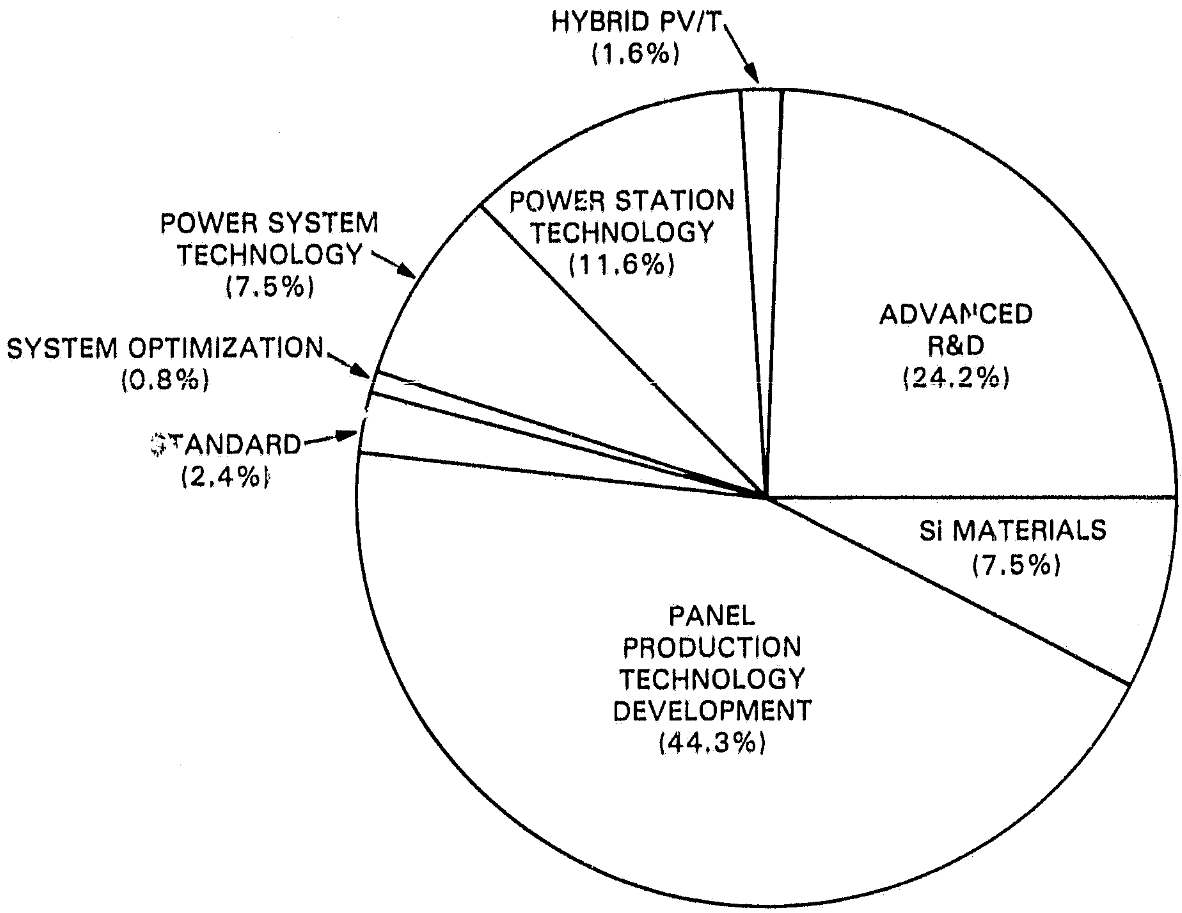

Figure 2-2. Sunshine Photovoltaic Project Funding
Pi-Chart in 1981

Table 2-4. Technology Task Breakdown

Task	Subtask
A. Mass-Production Technology Development of Solar Cells	(1) Silicon Material Technology -silicon material technology for producing low-cost chlorosilane -silicon material technology for hydrogen reduction using fluidized reaction
	(2) Silicon Sheet Technology -silicon sheet technology using casting process -silicon sheet technology using ribbon growth
	(3) Cell Fabrication Technology -cell fabrication technology using painting and printing -cell fabrication technology using ion-implantation and electroless plating
	(4) Module Assembly Technology
	(5) Testing Standards and Procedures of Solar Cells and Modules
B. Photovoltaic Power Systems Technology Development	(1) Development of Demonstration Systems -development of demonstration systems for private homes -development of demonstration systems for multi-family houses -development of demonstration systems for school facilities -development of demonstration systems for industrial process
	(2) Development of Photovoltaic/Solar Thermal Hybrid Systems
	(3) Central Power Station Technology -central power station technology for dispersed array location -central power station technology for centralized array location
	(4) System Support Technology

The management of the solar photovoltaic program is assisted by various steering committees made up of photovoltaic experts in industries and universities. The program reviews conducted by the Sunshine Headquarters appear to be programmatic rather than technical and on the single company/university basis. A joint program meeting on the other hand is technical where mutual exchange of information takes place. A typical meeting is the Japanese Photovoltaic Science and Engineering Conference which is held annually.

The photovoltaic project schedule, set by the Sunshine Project (as of 1981), is shown in Table 2-5.

Table 2-5. Photovoltaic Program Schedule

Tasks	Schedule 79	80	81	82	83	84	85	86
(1) MASS PRODUCTION TECHNOLOGY DEVELOPMENT OF SOLAR CELLS								
1) New Silicon Material Refining Plants			10t		100t		1000t	
2) Automated Panel Fabrication Technology Plants			500 kW Line		5000 kW line		50,000 kW line	
3) Test Standards and Procedures for Solar Cells								
(2) PHOTOVOLTAIC POWER SYSTEM TECHNOLOGY DEVELOPMENT								
1) Demonstration System			4 Systems	[For a Few Houses [For Corporated House [For School [For Factory			a-Si Solar Cell 1000 kW System	3 kW 60 kW 200 kW 200 kW
2) Central Power Station System				1000 kW x 2 Systems				
3) Photovoltaic/Thermal Hybrid System			30 kW System					
4) System Support Technology	3 kW	6 kW System						
(3) SOLAR CELL R&D								
1) CdS Solar Cell Development								
2) SnO_2 Solar Cell Development	Basic Research							
3) Amorphous Solar Cell Development								
(4) FUNDAMENTAL RESEARCH ON SOLAR CELLS			Basic Research					

Note: Hatched portion is for development, which is preceded by design phase and followed by operation phase.

These schedules appear to be changing in some instances as shown below. The goals shown in the following paragraphs are from the most recent (May 1982) NEDO document, whereas the schedules shown previously are from the 1981 NEDO document. The goals and progress status of each task are described below:

1. Low-Cost Silicon Material Experimental Refining System

   Goals (1984)

   Completion of a 10 ton/yr experimental refining system, capable of producing silicon shot (0.8-1.5 mm diameter) having resistivities of 30 ohm-cm (p-type) and 10 ohm-cm (n-type), and a carrier lifetime of approximately 10 μs. The main technical approach to achieve the goal is to produce trichlorosilane by hydrogenating silicon tetrachloride. Subsequently, the trichrosilane will be reduced in hydrogen in a fluidized bed reactor to produce solar grade silicon grains.

   Status

   Laboratory experiments are in progress for the production of trichrosilane, and the design of the fluidized bed reactor is in progress.

2. Solar Panel Production Pilot Plant

   Goals (1984)

   Completion of a 500 kW/yr PV panel production pilot plant. The nominal size of a panel is 1.2 x 0.4 m, and the nominal panel efficiency is 7.4%. Incoming solar cells to this plant will be the ribbon cells (10 cm wide), and the semicrystalline (cast) wafer cells (10 x 10 cm), having cell efficiency of 9%. These solar cells will be produced by the WET process (spray-on dopant and diffusion) and by the DRY process (ion implantation).

   Two solar cell process pilot plants, WET and DRY, and two solar cell material plants, ribbon and semicrystal, will have production capacity of 250 kW/yr each upon their construction.

   Status (1981)

   An experimental casting of semicrystalline silicon having an average grain size of >500 μm has been made to produce 5-cm diameter ingots. The efficiency of the solar cells fabricated from the cast and thin sliced wafers was no less than 9%. The construction of a 250-kW/yr pilot plant for casting and ingot slicing is in progress.

   An experimental ribbon puller has been tested for its operational characteristics. 10-cm-wide ribbon with 0.3 mm thickness has been pulled. The maximum pull rate was 2 cm/min and the maximum cell efficiency was 11%. Construction of a 250-kW/yr pilot plant is in progress.

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3. Solar Cell Test Standards and Procedures

Goal (1984)

Establish solar cell/panel test standards and procedures for performance and reliability evaluations. The accuracies of calibration standards and of the panel performance evaluation apparatus shall be 3% and 5%, respectively.

Status (1981)

Construction of a large solar simulator is in progress. Also, the design of environmental test chamber is in progress.

4. Demonstration Systems

Goals

Completion of four 3-kW residential systems in 1983, one 20-kW multi-residence system in 1984, one 200-kW school system in 1986, and one 100-kW factory system. These systems will be connected to the power grid so that the power conditioning system technologies and utility-interactive technologies can be developed.

Status

An experimental residential structure has been constructed and the test of roof-mounted solar panels, incorporated with a power conditioner has begun. A full-size structure will be completed in 1983. Construction of the 200-kW school system has been initiated at Tsukuba Science City, and a 100-kW factory system for lead-acid battery charging has been defined and its design is in progress.

5. Central Power Station System

Goals

Completion of one 200-kW distributed system in 1986 and one 1-MW central system in 1988. The system voltage will be 500 Vdc. The inverter efficiency will be >90% with harmonic content less than 2%.

Status

For both systems, 40-kW panel installation and PCS installation will be completed in 1983. Currently, both systems designs are being evaluated for their characteristics pertinent to year-round grid-connected operation.

6. Photovoltaic/Thermal Hybrid System

Goals

Completion of construction of a Fresnel lens concentrator PV/T system in 1984 having an electric output at 5 kW and thermal power output at 25 kW. Conversion efficiency shall be 10.5% electric and 30% thermal at 60°C.

Status

A 6-kW hybrid system has been under test since 1980. A 20-kW system has been designed, based upon the 6-kW system test results, and it is currently under construction.

7. Amorphous Silicon Solar Cell Research

Goals

Conduct amorphous silicon material research leading toward demonstration of 8 to 10% efficient solar cell (10 x 10 cm) in 1984.

Status

Fundamental research on amorphous silicon material characterization and thin film device fabrication are in progress at various research organizations including universities, companies, and government laboratories. An efficiency of 7.0% has been demonstrated by large area (10 x 10 cm) cells and efficiency as high as 8.15% has been reported with small area cells. Stacked, multi-bandgap cells have shown efficiencies of approximately 8.9%

The 1982 Sunshine Project tasks are summarized in Table 2-6.

Table 2-6. Sunshine Photovoltaic Project Tasks

TASK TITLE	ORGANIZATIONS	FY 82 (Ending March 1983) GOALS
Mass-Production Tech. Dev.	NEDO - Task Manager	
1. Si Material Technology		
(1) Low Cost Process	Osaka Titanium	Complete 10 t/yr plant construction
(2) Hydrogen Reduction	Shinetsu Chemical	Complete 10 t/yr plant construction
2. Panel Production Technology		
(1) Semi-Xtal Si Wafer	Osaka Ti/NEC	Complete 250 kW/yr plant construction
(2) Ribbon Si Wafer	Toshiba	"
(3) Dry Junction Process	Hitachi	"
(4) Wet Junction Process	Sharp	"
(5) Panel Prod. Tech.	Toshiba/NEC/Hitachi	Complete 500 kW/yr plant construction
3. Test Procedures & Std.	Kidenken	Large Solar Simulator construction
4. System Optimization	Central Power Res. Lab	Grid-connected System Analysis
5. Power System Tech. Dev.		
(1) Residential System	Fuji	Initiate 3-kW system test
(2) Multi-family System	Sharp	Complete 20-kW system construction
(3) School System	Hitachi/NEC	Complete compo. fab. & installation
(4) Factory System	Matsushita	Complete system design
6. Power Station Systems		
(1) Dispersed System	Cent. P. Res/Tokyo Electric Pwr.	Add 15 kW panels and PCS on existing 25 kW panels
(2) Central Station Systems	Cent. P. Res/Shikoku Electric Pwr.	"
7. Hybrid PV/T System	Sharp	Complete 20 kW system construction
Advanced R&D	Sunshine HQ - Task Manager	
1. Amorphous Si Cells	ETL/6 Universities/5 Companies	6% efficiency in '82, 8% in '84
2. Other	ETL/Matsushita/Tokyo Inst. of Tech.	

These tasks are arranged in a logical sequence for building the technology base which is required. Photovoltaic system production and application at a scale large enough to displace up to 10% of fossil fuels used in Japan by the year 2000 is to be accomplished using this technology base. The low cost silicon material production technology is somewhat down-played in the Project, indicating the Project perception of its low pay-off due to the high cost of energy required for silicon purification in Japan. The Panel Production Technology Task is proceeding according to the Sunshine Project Schedule, but with some potential delays.

It appears that the PV demonstrations and the system-level applications and tests are not extensive enough to acquire sufficient application experience for grid-connected systems for some time to come. The apparent sluggishness in the development of grid-connected PV systems may be a result of: (1) Sunshine Project's emphasis on component-level technology, (2) a sequential, ground-up project approach in arriving at the system outcome, (3) lack of PURPA (Public Utility Regulatory Policies Act) type regulation, and (4) no tax incentives for the user. The factors mentioned above are strongly coupled with the level of the Sunshine Project funding. However, the present level of funding appears likely to continue in the future without being affected by annual gyrations. The technology development portion of the funds, which is controlled by NEDO, comes from the special account of the Government budget to help solve the Japanese energy problems. This account is derived from the tax revenue on oil usage.

As far as the Sunshine Project's plans for industrialization are concerned, the construction of a 500-kW/yr pilot module plant, two 250-kW/yr pilot cell processing plants and two 250 kW/yr wafer production pilot plants are the most obvious. The construction is in progress, and the produced solar panels will be utilized subsequently by the Project for deployment of experimental solar PV systems, including one 1-MW central power system.

The market development for both the domestic and the international market is left to the industry itself. A token level involvement by the Sunshine Project is seen in the Australia-Japan photovoltaic project. The project plan is for Japan to furnish solar panels, up to several hundred kW, for Australia to test the panel performance, and to supply data back to Japan. Currently, panels of a few-kW equivalent are being planned for installation.

SECTION III

PHOTOVOLTAIC INDUSTRY

Japanese industry's interest in terrestrial solar photovoltaics dates back to the 1960s, when Matsushita Electric Co., was developing cadmium telluride solar cells. The ceramic form of this cell, under the name of SUNCERAM, was subsequently patented by Matsushita, but not marketed successfully. At the same time, the Sharp Corporation began developing single crystal silicon solar cell/ modules for terrestrial applications. In 1963, Sharp succeeded in mass-producing solar cells. A 242-W solar array installed for a lighthouse in Nagasaki was the world's largest terrestrial array in 1966. Sharp has continued the manufacturing and sales of solar cells/modules applicable to maritime safety and other small stand-alone systems at a moderately increasing rate.

With an initiation of the Japanese Scientific Satellite Program by the Institute of Space and Aeronautics Science (ISAS) in 1965, Japan formally started the development of space solar cells. The first solar-cell-powered satellite, Shinsei, was launched in 1971. Since that time, Japanese space solar cell production has steadily grown to meet the demand of both the ISAS and the National Aeronautics and Space Development Agency (NASDA). The current level of space solar cell production is estimated to be on the order of 10 kW/yr, and those cells are exclusively manufactured by the Sharp Co., at present.

Solar cell development for terrestrial application was formally initiated on a national level in 1974 with the formulation of the Japanese Sunshine Project. At that time, many companies and research institutions which have experience with the semiconductor research became involved in solar photovoltaic research.

To date, most of the companies are solely involved in the R&D activities rather than photovoltaic module production and sales, excepting, Sharp, Sanyo, Fuji, and Japan Solar Energy Co. (JSEC). Nippon Electric Co., (NEC), Hitachi, and Toshiba will begin their pilot production of cells and modules in 1983 under the Sunshine Project. The 1982 production capability of Japanese companies is estimated at a total of 2.0 MW/yr, and the total shipment is estimated at 1.7 MW/yr. Thus, the Japanese share of photovoltaic module production is ~18% of the current worldwide capability. Eighty percent of the 1.7-MW shipment is estimated to be for consumer electronics, such as pocket calculators, watches, and toys. The remaining applications are for photovoltaic demonstrations in the Sunshine Project, and remote stand-alone applications at domestic as well as foreign sites.

Amorphous silicon technology became the leading technology for photovoltaic cells/ modules for consumer electronics in a very short period of concerted effort. However, Czochralski (Cz) silicon technology evolved from the space cell technology is still the technology used for other photovoltaic modules. With the completion of a Sunshine Project pilot plant, semicrystalline and ribbon cells/modules will be produced at 500 kW/yr in 1983. In addition, there is a strong push by the Sunshine Project to make amorphous silicon cells/modules a viable alternative to Cz modules. Currently, Japan holds an edge in amorphous silicon photovoltaic production and experience, especially in the glass/ITO/a-Si/Al cells.

In the following paragraphs, representative Japanese companies which are and will be in photovoltaic cell/module production are described.

Sharp Corporation

Sharp, which installed a 242-W solar array for a lighthouse in 1966 (the largest terrestrial array at that time) has been manufacturing Cz solar cells/ modules for terrestrial and space applications during the past 15 yrs. The terrestrial applications include maritime safety, weather stations, agricultural, and other stand-alone applications. A recent, rapidly growing addition is pocket calculator cell modules.

The production capability for the calculator Cz modules is estimated at 1.5 million modules per month in 1982, equivalent to 500 kW/yr (at 6% AM1). Additional photovoltaic production capacity for Cz modules is approximately 200 kW/yr, including 10 kW/yr for space applications. Sharp has been the manufacturer of most solar cells for the Japanese scientific and applications satellites in the past, and is the sole supplier for future satellites. The total shipment of cells/modules is estimated at 700 kW/yr in 1982, including less than 100 kW for export.

Production and shipments will increase in 1983 consistent with the completion of the 250-kW/yr Sunshine cell process plant. Moreover, amorphous silicon production would commence at some unknown future time, when Sharp completes installation of amorphous silicon cell production equipment, manufactured by ECD, Michigan, capable of producing cells at 3 MW/yr.

Sharp has also been developing a 30-kW PV/T system for the Sunshine Project using point focus Fresnel lenses.

Japan Solar Energy Co. (JSEC), Kyoto Ceramic Co.

JSEC is co-owned by Kyocera (51%), Mobil Oil (39%), and Matsushita (10%) for the production of EFG ribbon cells, under Mobil-Tyco license. The silicon ribbon production, therefore, is not funded in any way by the Sunshine Project, and therefore, it is a private venture. Currently, JSEC owns 12 ribbon pullers (single ribbon/puller), each capable of producing quality ribbons (4 in. wide) at 2 cm/min, 80% yield, although the pullers are operating at 50% capacity because of the limited market. JSEC produces its own modules using ribbon silicon material for application to remote stand-alone systems, street lighting fixtures, and battery chargers, under the trade name of "Son of Sun."

The production capability of JSEC is estimated at 300 kW/yr in full operation, and module shipments are estimated at 180 kW in 1982.

In addition, Kyoto Ceramic Co. (Kyocera) is entering into the production of semicrystalline silicon cells/modules using wafers purchased from Wacker-Silso. The potential market is for irrigation pumping and medical applications in developing countries.

Toshiba

Toshiba has been developing its ribbon silicon technology for the Sunshine Project during the past several years to supply the ribbon silicon material required by the Sunshine module pilot plant. For the Project, Toshiba is responsible for completing a ribbon silicon material plant capable of producing 250 kW/yr of silicon ribbons starting in 1983. The construction of the ribbon plant is now in progress. According to recent information, Toshiba successfully pulled a 4-in.-wide ribbon at a rate of 2 cm/min. However additional development is required to accomplish high yield production of similar ribbons. Toshiba is also responsible for completing a 500-kW/yr Sunshine module plant jointly with NEC and Hitachi. The plant is located on Toshiba's land and its construction is scheduled for completion in 1983. Toshiba's photovoltaic production capability and photovoltaic shipment are zero in 1982, but projected to be about 100 kW/yr in 1983 when the ribbon and module plants are completed.

Nippon Electric Co. (NEC)

Nippon Electric Company, which is mainly involved in the production and sales of communication apparatus and systems, has been manufacturing solar cells/modules for remote repeaters and communication equipment. The company also has experience with solar photovoltaic panels for space satellites. Since the initiation of the Sunshine Project, the company became involved in terrestrial solar photovoltaics. Recent emphasis is in the cast silicon technology (jointly with Osaka Titanium) and amorphous silicon material technology. A 250-kW/yr cast silicon pilot plant is now under construction for the Sunshine Project. Upon its completion in 1983, NEC will start producing 100 kW/yr of semicrystalline silicon wafers in early 1983. Current module production capability, which is with Cz silicon, is estimated at 100 kW/yr, and shipments at 80 kW/yr.

Hitachi, Ltd.

Hitachi initiated its photovoltaic R&D effort for the Sunshine Project by making use of its capability in electronic and electric R&D. Hitachi is scheduled to complete a 250 kW/yr solar cell fabrication pilot plant using an ion implantation machine in 1983. Following its completion, 100 kW/yr of both the semicrystalline and ribbon cells will be fabricated starting in 1983. Hitachi's current shipment is less than 10 kW/yr of Cz silicon cells/modules. Hitachi is also constructing a 200-kW school demonstration system with NEC for the Sunshine Project.

Sanyo Electric Co.

Sanyo is a leading company in Japan in manufacturing and marketing electric and electronic hardware for consumers. Recently, the company management has identified the solar energy business as a worthwhile venture for the future. Thus, both solar thermal and solar photovoltaic technology development were initiated. Sanyo's solar photovoltaic R&D, which started on corporate funds, unlike the majority of Japanese photovoltaic R&D, has been concentrated on amorphous silicon solar cells / modules. Sanyo advanced steadily to recently building a new plant, at an investment of $50M, to house its rapidly-expanding amorphous silicon solar cell/module manufacturing facility. Currently, approximately 1.5 million calculator modules are manufactured per month by Sanyo. This production volume is equivalent to 500 kW/yr by converting the produced module area to output electric power, assuming that the same module has an efficiency of 6% AM1.

A 100-kW equivalent of Sanyo's amorphous silicon modules is estimated to be shipped to its own Consumer Electronics Division in 1982, and 400 kW to Casio, GE, and Formosa for pocket calculators. A new line of amorphous silicon solar cell products is 10 x 10 cm chargers for rechargeable batteries to be used with portable electronic equipment. Power modules (40 x 50 cm) for roof-top and other applications would be a future product.

Fuji Electric Co.

Fuji Electric Co. has been traditionally involved in large electric power equipment in contrast to small consumer electronics. Fuji's recent involvement in amorphous silicon solar cell R&D, mostly with the Sunshine funds, appears to be heading toward grid-connected power applications. However, the company's current photovoltaic product is pocket calculator modules. Present production capability is estimated at 250 kW/yr with shipments at 200 kW/yr. Power modules have also been built for evaluation purposes. Fuji is also constructing a residential roof-top array for the Sunshine Project.

Mitsubishi Electric Co.

Mitsubishi was involved in the fabrication of solar panels for some of the Japanese scientific satellites in the past. Its current photovoltaic activity is advanced research for cascaded amorphous cells, i.e., a-SiC/a-Si:H/a-SiGe.

Sumitomo Electric Co.

The company has been developing Fresnel lens solar concentrator photovoltaic modules for the Sunshine Project. A 10 x 6 array (3.4 m x 2.1 m) of Fresnel lens/GaAs cells was recently put on test. The company is likely to continue its effort at the present level.

Companies described above are not the exhaustive list of all companies involved in the photovoltaic research and development in Japan. In the following, some additional companies are listed together with their photovoltaic activity:

Osaka Titanium:	Silicon purification, cast silicon wafer fabrication
Komatsu:	Silicon purification, Cz growth, cell/module fabrication (200 kW/yr)
Shinetsu:	Silicon purification
Kodenshi Kogyo:	Cz cell/module fabrication and sales, toy modules
Mitaka Electronics:	SnO_2/a-Si cell research
Taiyoyuden:	Cz cell/module fabrication
Matsushita:	CdS/CdTe cell/module fabrication
Teijin:	Amorphous silicon cell/Kepton film

SECTION IV

PHOTOVOLTAIC RESEARCH

In 1979, upon the introduction of the new thrust "Accelerative Promotion of the Sunshine Project," the scope of photovoltaic research expanded, especially in the area of amorphous silicon solar cell research. As a result, the current research is conducted not only at Electrotechnical Laboratories, which is a government research laboratory and at five universities, but also at seven industrial groups. The research funds for 1982 of \$8.0M include \$7.0M from the Sunshine Project and \$1.0M from the Ministry of Education. Approximately 80% of the research funds goes to amorphous silicon cell research as it was in 1981. The industry group conducts the applied research, and the non-industry organizations conduct the fundamental research. Both research activities are managed directly by the Sunshine Project Headquarters. Participating organizations and their research activities, which are described in the following pages, are shown in Table 4-1.

Table 4-1. Photovoltaic Research

Organization	Activity
Electrotechnical Laboratories	Amorphous materials and technology
Osaka University	Characterization of GD-aSi properties
Kyoto University	Theoretical study on electronic states in a-Si
Hiroshima University	Experimental study of gap states in a-Si
Tokyo Institute of Technology	Properties of junction interface in a-Si
Kanazawa University	Studies of a-Si-based new materials
Fuji Electric Co., Ltd.	a-Si solar cell area enlargement technology
Komatsu Electronic Metals Co.	Low cost production process for mono-silane
Kyoto Ceramic Co., Ltd.	a-Si solar cell on ceramic substrate
Mitsubishi Electric Co., Ltd.	Multi-Junction a-Si solar cell
Sanyo Electric Co., Ltd.	Integrated-type a-Si solar cell
Sumitomo Electric Co., Ltd.	Improvement of a-Si films by plasma separation
Teijin	a-Si solar cell on flexible substrate

The highlights of the photovoltaic R&D are described in the following:

1. Electrotechnical Laboratory

Location: Ibaraki, Japan

Contact: Dr. Katsuya Nakayama, Manager
Extremal Technology Division

The Electrotechnical Laboratory is the largest of 16 national research laboratories belonging to the Ministry of International Trade and Industry. The ETL is currently staffed by 730 people, of which, 564 are research staff and budgeted at $39M to conduct basic and applied research in four broad areas: (1) solidstate physics and materials, (2) information processing, (3) energy, and (4) standards and measurements. ETL is the technological leader in national research and development projects including the Sunshine Project. The financial data are shown in the pi-chart Figure 4-1. It should be pointed out that the Sunshine Project expenses are for capital equipment and procurements, and do not include labor cost which is shown under the category of personnel expenses in the pi-chart. Therefore, the total usable ETL budget for the Sunshine project, of which the Sunshine PV program is a part, is estimated at $5.2M. Although further breakdown of this budget was not available, the PV portion of the budget at ETL is estimated at between 2 and 3 million dollars.

ETL functions as a technical advisor for MITI in the Sunshine Project for planning and program direction. It also conducts in-house advanced research, especially in the area of amorphous silicon solar cells and standardization. There are 23 professionals engaged in the in-house PV research. In addition, approximately 10 research associates are invited from foreign countries, Japanese industries and universities.

The laboratory is well equipped for cell characterization measurements and reliability testing. Solar cell panels which are manufactured by various manufacturers are on the roof of the building for outdoor testing.

Some of the most noteworthy recent progress is in micro-crystalline silicon formation on amorphous silicon film. According to ETL, a 1.2 cm^2 a-Si:H cell fabricated by Fuji using the above mentioned film formation process produced 7.8% efficiency. ETL is also involved in the joint Australia-Japan PV project in which Japanese manufacturer(s) are to provide a few kilowatts of solar cell panels and Australia is to test their performance in the field. In addition, ETL appears to be in a leading position to guide Japanese PV standardization, which is not coordinated at present, and consequently Japanese manufacturers are depending on available information including the JPL/FSA module testing procedures.

ETL is a highly influential organization in Japan through its strong connection with MITI and its reputation in technology accomplishments. Such accomplishments, as in the past "Pattern Recognition Project," are now becoming visible through industrial automation which is founded on computer technology, robotics, and optical sensing development under the above mentioned project.

Scale	Staff	721 (Research Staff 564)
	Budget	§ 38,977,000 ($1 = ¥229)
	Buildings	71,384 m²
		(Tsukuba I 63,374 m²)
		(Tsukuba II 966 m²)
		(Osaka 4,525 m²)
		(Takasago 2,519 m²)

Budget for Fiscal Year 1982

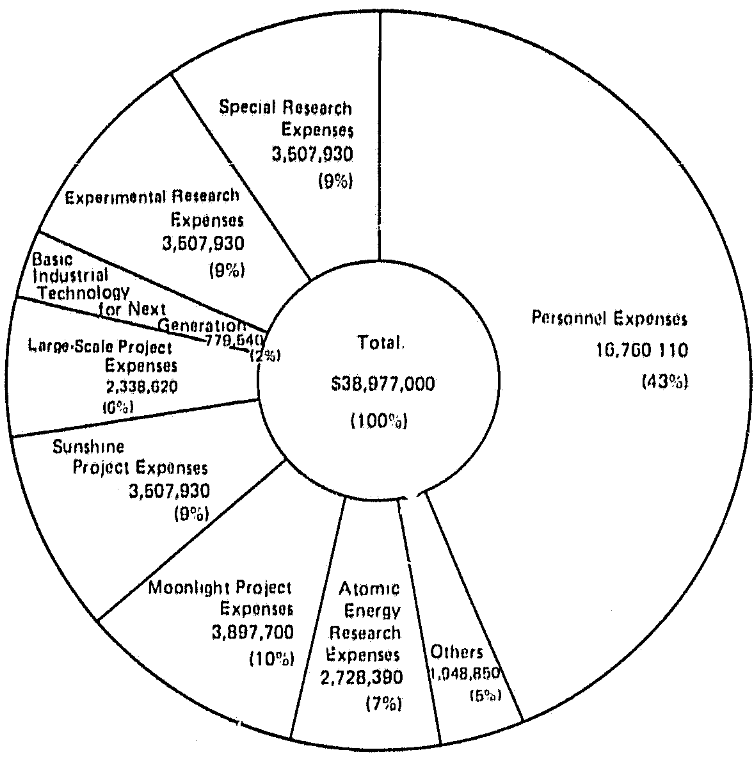

Figure 4-1. Personnel and Financial Data of ETL for Fiscal Year 1982

2. Osaka University

Location: Toyonaka, Osaka

Contact: Dr. Yoshihiro Hamakawa
Professor of Electrical Engineering Department,
Faculty of Engineering Science

The Semiconductor Laboratory, which Dr. Hamakawa supervises, is one of many laboratories at Osaka University which has a total of 21,000 students. Dr. Hamakawa's laboratory is staffed by 5 faculty members, and has 13 graduate students, 9 undergraduate students and visiting scientists.

The research projects are: (1) Modulation Spectroscopy and Optical Properties of Semiconductors, (2) Semiconductor Heterojunctions and Their Applications, (3) Amorphous Semiconductors and Their Applications, (4) Ferroelectric Thin Films and Their Applications, and (5) Thin Film Electroluminescence. Amorphous silicon solar cell work which is performed in the project number (3) above, is funded by the Sunshine Project and also by the Ministry of Education. Approximately 10 out of the total 22 students are involved in the amorphous silicon research, of which the amorphous silicon solar cell research is a part.

Dr. Hamakawa's laboratory is the leader of the amorphous materials research encompassing the solar cells, photoluminescent devices, film deposition, film characterization, and plasma diagnostics. His laboratory is well equipped with modern laboratory apparatus to perform all of the above research. An inline, five chamber amorphous silicon disposition apparatus, 2-m long, 1.5-m high and 1-m deep, has been installed recently. I believe that this is the only in-line system solely owned by a university today. Hamakawa's cell efficiency record of 8.04% was only recently broken by Sanyo, which achieved 8.15% with an ITO/pin a-Si:H/Al owing to Hamakawa's guidance, and most recently by RCA which achieved 10.1%. Dr. Hamakawa is also influential to Japanese PV and amorphous silicon research as a member of various advisory committees for the Government and industry.

3. Kyoto University

Location: Sakyo-ku, Kyoto

Contact: Dr. Hiroyuki Matsunami
Professor, Electronic Engineering Department,
Faculty of Engineering

Professor Matsunami's laboratory has been active in advanced silicon cell research for a good many years. The subjects of Professor Matsunami's research activity are: (1) Preparation of Optoelectronic Materials, (2) Solar Cells, and (3) Characterization and Assessment of Semiconducting Materials. Current solar cell research activity includes the SiO_2/p-Si inversion layer solar cells which utilize Mg/SiO_2/p-Si MIS structure. Efficiency as high as 13.6% was achieved with this structure.

Professor Matsunami's laboratory is adequately equipped to perform thin film depositions and laboratory solar cell fabrication.

4. Hiroshima University

Location: Hiroshima 730

Contact: Masataka Hirose

The university is conducting the "Study on the Electronic Density of States in the Mobility Gap of Amorphous Silicon" for the Sunshine Project by analyzing C-V characteristics of metal/SiO_2/a-Si MOS structures. The measured gap states are correlated with the film growth parameters to investigate the incorporation process of structural defects during the film growth. They have demonstrated that the surface states hardly influence the bulk gap states distribution when determined by the conventional C-V method using an amorphous silicon MOS structure.

They have also reported substitutional doping of a-Si_xN_{1-x}:H with B or P by preparing the film in a glow discharge of SiH_4, NH_3 and H_2 with appropriate dopant.

5. Tokyo Institute of Technology

Location: Meguro-ku, Tokyo

Contact: Dr. Kiyoshi Takahashi
Professor, Department of Physical Electronics

Tokyo Institute of Technology founded in 1881 [illegible] 3,200 undergraduate students, 1,850 graduate students and a total of 1,000 fac[illegible]ty members. Professor Takahashi manages his Solid State Electronics Laboratory jointly with Professor Konagai. The laboratory has two additional faculty members who supervise the graduate study of eight graduate students. Major activities in the laboratory are: (1) MBE application to optoelectronics, (2) GaAlAs/GaAs heterojunction formation by LPE, and (3) amorphous silicon physics and devices. The amorphous silicon work is funded by the Sunshine PV Project.

This laboratory is well equipped to conduct quality thin film research. A dc glow discharge apparatus, 7.5 cm in. diameter and 70 cm long, which is to demonstrate large throughput a-Si fabrication, is also in operation. Variations of film properties along the length and the width of the prepared samples are being correlated with the efficiency of cells prepared in the apparatus.

6. Kanazawa University

Location: Kodatsuno, Kanazawa

Contact: Professor M. Suzuki

The university is investigating chalcogenide amorphous semiconductors as a promising material for PV applications since the optical properties of chalcogenides are easily controlled by changing their material compositions. Recently the researchers at the Kanazawa University found that the conductivity of chalcogenide amorphous films can be increased by several orders of magnitude by thermal diffusion of copper ions below glass transition temperature. Such a diffusion is postulated to be due to chemical reactions at the interface between metals and the amorphous film, according to the paper presented at the 3rd Photovoltaic Science and Engineering Conference in Japan, May 1982.

The researchers also reported an increase of the photoconductivity of an amorphous silicon film by co-sputtering P or B with Si in a rf-biased sputtering apparatus.

The highlights of this conference are described in Section V.

7. Fuji Electric Co., Ltd.

Research objective: Develop large area (10 x 10 cm) amorphous silicon solar cells having efficiencies 8 to 10% by 1984 applicable to grid-connected systems.

Progress: Technologies for fabricating both p-i-n and n-i-p amorphous silicon solar cells are being developed. The effect of the cell area on cell efficiency has been investigated for cell areas between 1 cm^2 and 100 cm^2. The cell efficiency decreased as much as 25% as the area was increased.

8. Komatsu Electronic Metals Co., Ltd.

Research Objective: Develop a manufacturing method for a low cost monosilane as a raw material for the production of amorphous silicon solar cells.

Progress: The following reaction process has been identified to be tested and the construction of an experimental reaction chamber is in progress:

(1) Produce lithium by electrolysis of lithium chloride-potassium chloride molten salt.

(2) Hydrolyze the produced lithium.

(3) Generate monosilane by reaction between the lithium hydride and silicon tetrachloride.

9. Kyoto Ceramic Co., Ltd.

Research Objective: Evaluate various ceramic materials as candidate substrate for amorphous silicon solar cell.

Progress: Experimental amorphous silicon solar cells were fabricated on various ceramic substrates having varied surface roughness. The morphology of the amorphous silicon film is being investigated.

10. Mitsubishi Electric Co.

Research Objective: Develop a high-efficiency multijunction a-Si/ a-SiGe amorphous solar cell.

Progress: Two-layer as well as three-layer multijunction amorphous solar cells have been fabricated in the laboratory for relatively small area ($0.25cm^2$) devices. The efficiencies were 7.7% and 8.5% with two- and three-layer cells, respectively. Also, the photoninduced degradation effect has been investigated. The result showed that the degradation of SiGe multijuntion cells is similar to that of conventional amorphous silicon cells according to the recent report at the DOE/SERI Workshop on Amorphous Solar Cell Stability in San Diego, California, September, 1982.

11. Sanyo Electric Co., Ltd.

Research Objective: Develop the basic technology necessary for the mass production of low-cost, high efficiency amorphous silicon solar cells with large cell areas.

Progress: The fabrication method for integrated-type amorphous solar cells using the consecutive, separated deposition chamber has been well established so that Sanyo is manufacturing pocket calculator and watch modules as it was described previously. In the Sunshine research, Sanyo is investigating fundamental properties of amorphous silicon films including gap state density, conductivity, photo-response and photon-induced degradation. Sanyo repeatedly found the importance of its unique chamber to avoid undesirable cross contamination. Sanyo as well as other amorphous silicon cell manufacturers are now expressing confidence in realizing stable cells at efficiencies between 8 and 10% by 1984.

12. Sumitomo Electric Co., Ltd.

Research Objective: Unknown

Progress: "Characteristics of Sohottky Barrier Diodes" was reported at the 3rd Photovoltaic Science and Engineering Conference in Japan, 1982. The sample was prepared by a glow discharge process in a mixture of PH_3 and SiH_4. The diodes were of sandwich configuration of Pt or Au/a-Si/ crystalline silicon.

13. Teijin

Research Objective: Establish the basic technology for preparation of low-cost amorphous silicon solar cells on flexible polymer films. The goals for FY 1990 are:

(1) Cell efficiency > 8% (cell area: $100cm^2$)
(2) Production yield > 90%
(3) Cell cost < 40 cents/Wp

Progress: Amorphous silicon cells were fabricated on a polyimide film (Kapton) for the investigation of cell characteristics. The cell having a Kapton/sputtered SS/p-i-n, a-Si/ITO structure showed a maximum efficiency of 6.03%. The importance of the morphology of the film which is influenced by the substrate morphology was pointed out during the 3rd Photovoltaic Science and Engineering Conference.

SECTION V

3RD PHOTOVOLTAIC SCIENCE AND ENGINEERING CONFERENCE (PVSEC)

The 3rd PVSEC Conference was held at the Kyoto Kaikan (Convention Center) in Kyoto between May 19 and May 21, 1982. This is a Japanese PV Conference jointly sponsored by the Japanese Applied Physics Society, Japanese Academy of Science, and Electric and Electronic Research Coordination Committee.

According to the announcement made at the closing session of the conference, the next conference will become the First International Photovoltaic Science and Engineering Conference sponsored by Japan, November 13-16, 1984.

The conference was attended by approximately 120 scientists and engineers representing the Japanese photovoltaic industries, universities and research institutions. The bulk of the subjects discussed during the conference were on the results of research sponsored by the photovoltaic part of the Sunshine Project, and the Grant-In-Aid of Special Research on Energy from the Ministry of Education. Management level personnel did not attend the conference because it was not a program review.

Four U.S. delegates, P. Maycock, Photovoltaic Energy Systems, Inc.; K. Shimada, JPL; D. Carlson, RCA and S. Wagner, Princeton were present.

Sessions were divided into four major areas: (1) Silicon Solar Cells, (2) Compound Semiconductor Solar Cells, (3) Systems and Arrays, and (4) Amorphous Solar Cells.

Two invited papers were given, P. Maycock on "Photovoltaic Technology Progress and Industrialization" and K. Shimada on "Cost Estimates for Flat Plate and Concentrator Collector Arrays." In addition, D. E. Carlson gave a post-deadline paper entitled "Major Problems Still to be Solved in a-Si Solar Cells."

The invited papers were of considerable interest among the Japanese PV industries since they are about to enter into a scaled-up production and deployment of PV power systems in addition to the existing PV applications to consumer electronics. According to discussions in conjunction with our talks, the Japanese development of the grid-connected PV systems has had a slow start because of the lack of: (1) tax incentives, (2) PURPA-type regulations, (3) availability of land for central PV systems, (4) remote sites for stand-alone applications, and (5) PV system deployment experience.

Highlights of the conference are:

(1) Silicon Solar Cell Session

The subjects covered in this session included technologies for both space solar cells and terrestrial solar cells. Sharp reported its work for ultra thin silicon space solar cells that produced an efficiency of 13.6% with 2 x 2-cm^2 textured, BSF, BSR cells. The cells have a calculated specific weight of approximately 1 kg/kW. Very little was reported on the progress of terrestrial cell fabrication process since the work was not in the research category which was being discussed in this conference.

(2) Compound Solar Cell Session

A large group of compound solar cell types are being studied by various research organizations. Screen printed CdS/CdTe cells by Matsushita produced 5.2% conversion efficiency. Hokkaido University reported a conversion efficiency of 9.2% with a $Cu_2Se/Cu_2Te/Si$ solar cell. A 3-terminal, stacked GaAlAs/GaAs cell, which is mechanically in series but electrically in parallel, was fabricated by the Nagoya University researchers using MOCVD. The cell efficiency was 5%. A threestack cell, GaP, AlGaAs/GaAs, AlGaAsSb/GaSb is being studied at Kyoto University. The calculated theoretical efficiency is 50%, and three individual cells have been fabricated and investigated.

(3) System and Array Session

Concentrator cells/modules were discussed in this session. NEC reported its achievement of 17% efficiency at 25X, 28°C with a p+n n+, 2.3-in.-diamenter silicon cell. Sumitomo reported on an experimental GaAs cell (2cm diameter) applicable to PV/T systems. The efficiency was 22.2% at 149X and 18.8% at 320X. The cell is mounted on an aluminum substrate via an insulating layer, such as is done in printed circuits. The assembly is attached to the water-cooled duct via an adhesive. Other concentrator collector work was reported by Sumitomo. This collector utilized 30 cm x 30 cm Fresnel lenses arranged in a 7 x 3 rectangular array. Although the cell efficiency was 16% at 25X (geometrical concentration = 200), the array efficiency was only 2.1%. This was caused by the poor lens efficiency, only 15%, according to Sumitomo.

Another notable system experiment is that of Sanyo using 513 of Sanyo's amorphous silicon solar panels. Each panel consists of a 4 x 5 parallel-connected matrix of 10cm x 10cm amorphous silicon power modules each of which has 9 series connected cells in an integrated circuit. The efficiency of the test module was 5.2% but the array-level efficiency averaged over one month in August, 1981, was between 2.3 and 3.1%. Some degradation (∿10%) occurred initially, but performance has been stable thereafter according to Sanyo.

(4) Amorphous Silicon Solar Cell Session

The session occupied 30% of the entire PVSEC indicating the traditional emphasis of this conference on amorphous silicon, and the importance of the a-Si technology in the Japanese PV program.

The sessions were divided into three major areas: (1) Preparation Process, (2) Characterization, and (3) Device Physics.

Although the principal a-Si fabrication process is the glow discharge, other low-key efforts in dc discharge were reported both by Fuji and the Tokyo Institute of Technology. The dc discharge could be cost effective because of its potentially large throughput capability, but the low yield coupled with the non-uniformity of the produced film may override the advantage. Also, a possibility of doping amorphous silicon by co-sputtering P or B with Si was discussed by Kanazawa University. Another interesting doping method was presented by Hiroshima University. This method is a substitutional doping of a-Si_xN_{1-x}:H using PH_3 or B_3H_6. The study of vibrational spectra of doped a-Si_x N_{1-x}:H suggests that the doped boron atoms are incorporated not only at silicon sites surrounded by four silicon atoms but also at other sites where BN bonds are created. Phosphorous doping has not been as successful as boron doping to date with this method.

The importance of the separate-chamber deposition during the preparation of amorphous films was repeatedly emphasized by Sanyo. For example, the efficiency of the Glass/ITO p (a-SiC)-i-n a-Si/Al cell was 7.9% when prepared in separate chambers in comparison with 5.79% in a single chamber because of cross doping of the i-layer by the dopant used in the preparation of the previous layer. The Tokyo Institute of Technology suggested that the nip structure is in fact an np^-p or $np^{--}p$ structure, and the pin cell being a pn^-n unless cells are prepared in separate chambers.

The effect of foreign elements near the p-layer of the amorphous silicon solar cell was discussed by Osaka University. According to this study, SnO_2 is better than ITO as a transparent electrode material because a detrimental effect exists within the p-layer due to ITO.

According to Sanyo's theoretical calculation of an a-Si cell using the "shifted-U" distribution for the gap states, the maximum efficiency is 12.5%. Also, the theory predicts that efficiency as high as 20% is achievable with a multi-bandgap cell utilizing a-SiC, a-SiN, a-Si and a-SiSn.

Another notable item was the fabrication of a-Si cell on a flexible Kapton film as reported by Teijin. The efficiency, which depends on the substrate morphology, was 6.0% with a Kapton/sputtered SS film/p-i-n a-Si/ITO cell.

In summary, the conference was well attended and the quality of the papers was excellent, especially in its experimental aspects. Parametric investigation, which is time consuming, was done carefully and thoroughly and was presented comprehensively. Obviously, the conference is more scientific than engineering. However, a good balance between science and engineering seemed to have been maintained.

SECTION VI

CONCLUSIONS

The results of the recent surveys of the Japanese photovoltaic activities which were compiled during Shimada's visit to Japan in May-June, 1982 are summarized as follows:

(1) The main driving force for the Japanese photovoltaic technology is the Sunshine Project of the Ministry of International Trade and Industry, which funds \$29M (at 230 yen/dollar) in FY 82 (April 1982-March 1983). The total available funds for the Project, including labor, which is heavily subsidized by the industries and is fully compensated by the parent institutions of non-profit organizations, are estimated at \$60M in FY 82.

(2) An experimental automated PV module production facility for the Sunshine Project rated at 500 kW/yr (one shift) is scheduled to be completed by March 1983. The construction of this facility is in progress, although some slippage ($\sim$6 months) in completion date may occur.

(3) The products from the above named production facility will be procured by the government for the PV system application and test activities which have had a slow start with respect to that of the U.S. Program.

(4) Total production capacity of photovoltaic modules is estimated at 2.0 MW/yr in 1982 and the total shipment at 1.7 MW/yr. Approximately 50% of the shipment is for pocket calculators and consumer electronics.

(5) Amorphous silicon solar cells are currently marketed by Sanyo and Fuji at a rate of two million modules per month for consumer electronic applications in pocket calculators and watches.

(6) Amorphous silicon solar cell technology, which receives \$7.0M from the Sunshine Project and approximately \$1.0M from the Ministry of Education, is making credible progress showing cell efficiencies as high as 8.15% with small area cells and 6.35% with large area (100 cm^2) cells.

(7) Uncertainties in the future PV market for the Japanese PV manufacturers exist, and the PV manufacturers appear to be in favor of increased government procurement, at least for the next few years.

(8) PV module and system cost is downplayed in the Project, partly because the Japanese electricity cost is nearly twice that of the U.S., and partly because the Japanese PV industry is not ready - at least for several years - for international competition.

(9) Japanese interest and effort in PV standardization is rapidly increasing, indicating planned near-term entry into large-scale cell/module fabrication.

(10) Currently, there is no tax credit arrangement nor PURPA-type regulations in Japan for photovoltaics. The NEDO officials indicated the need for such regulations for an increased PV deployment in the future. Solar hot water systems, however, receive tax credit, and therefore residential roof-top units are widely noticeable.

In summary, the Japanese photovoltaic R&D activities will continue in the future under the steady funding from the Sunshine Project. Single and multi-crystal silicon solar cell/module technologies are targeted for large-scale production using currently available technologies. Research in amorphous silicon solar cells is stressed over other advanced solar cells in the Sunshine Project, and the production experience is rapidly increasing because of the strong participation by private companies for manufacturing and marketing of calculator-type modules.

Also, the establishment of a broad technology base for crystal, multicrystal and amorphous silicon technologies is an implicit long-range goal.