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ARRAY AUTOMATED ASSEMBLY TASK. PHASE 2

Low Cost Silicon Solar Array Project

Quarterly Technical Report No. 1, October—December 1977

By
Gregory T. Jones

MASTER

January 1978

Work Performed Under Contract No. NAS-7-100-954865

Sensor Technology, Incorporated
Chatsworth, California

U.S. Department of Energy

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Solar Energy

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ABSTRACT

Work on Phase 2 of the Array Automated Assembly Task, a low-cost silicon solar array project, was conducted during this quarter. This project covers the period from October 1st, 1977 through December 31st, 1977.

An automated process sequence was defined, process steps were organized into groups for investigation, and data was gathered and analysis begun for four process groups. A solar cell test data acquisition system was designed. This system will automatically sample and plot the electrical performance of solar cells and will also be adaptable for solar cell module electrical performance. Wafer surface preparation equipment has been modified for this automation program. The equipment is now ready to process 90 mm diameter silicon wafers in sample volume for a projected automated process analysis. The laser trimming and holing operation has been defined. A laserscribe computer program for trimming a hexagon and cutting a central hole from a round silicon wafer is being negotiated for procurement. Information on the spray on dopant process is being gathered. Spin-on equipment is being used to test the viscosity, thickness of application and concentration of several dopants for use in the spray on dopant process. Preliminary work on SAMICS has started. A SAMICS report will be made and sent to the Jet Propulsion Laboratory after analysis of each process group is complete.

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I. INTRODUCTION

Analysis of an automated solar cell module production process sequence is the overall goal of this program. This study for Phase 2 of the Array Automated Assembly Task is based on a number of assumptions: 500 MW/year in 1986 will be produced at a cost of \$.22/watt for silicon wafer material and at a cost of \$.50/watt for the finished module. The solar cells will have a 14.5% photovoltaic energy conversion efficiency in 1986 with an overall process yield of 95%. The solar cell module will have dimensions of 2' x 4'. Each module shall contain 119 solar cells and produce approximately 90 watts at 28°C and at 100 mw/cm².

As a result of the above, nominal throughput is expected to be 5.56 million modules per year or 696 million solar cells per year.

The program objectives and general work outline will be approached in the following manner: The solar cell module process sequence will be critically analyzed for cost effectiveness, quantity throughput and reproducibility of products. Each process step will be ranked according its technology readiness, degree of development required, input/output criteria, and significance to the overall process sequence. Process steps most needed to make the process viable will be developed. The readiness of each process step will be demonstrated.

II. TECHNICAL DISCUSSION

A. Array Automated Assembly Production Flow

Sensor Technology's approach to Phase 2 of the Array Automated Assembly Task consists of analyzing present technology for the automation of process steps to meet the 1986 goals. A conceptual picture of an array automated assembly production flow is shown in Figure 1. Silicon wafers are received in cassettes, sample inspected and loaded into a wafer carrier basket. The basket moves to surface preparation on a conveyor. The silicon wafers are texturized cleaned in a cascade rinse system, and dried. The texturized wafers are automatically loaded from the cassettes onto a conveyor where they move to the spray-on dopant process. This process sequence consists of spray on n^+ and p^+ dopants in a differential pressure chamber. An alternate process step to be considered consists of a PH_3 diffusion on a conveyor. The wafers move to a dopant drive in step. Excess dopants are removed. Then the wafers move along to the back metallization and printing operations. At the printing step the hexagon pattern is printed on the wafers. The wafers then pass through an electroless nickel plating process tank and resist removal cleaning operation. They are unloaded from jigs onto a conveyor for laserscribing. The laser trims and holes the wafers and moves them along to a solder flow machine. After solder

coating and flux removal, the solar cells are given a silicon nitride anti-reflective coating using a chemical vapor deposition process. The finished solar cells are automatically tested to determine electrical performance and mechanical integrity and then grouped accordingly. The grouped solar cells are loaded into hoppers ready for solar cell array subassembly. The solar cell array subassembly consists of dispensing whole hexagonal solar cells and half hexagonal solar cells onto a printed circuit sheet. The solar cells drop into a tab which passes through the hole in the center of each cell and induction soldered. The interconnected cells are laid on a glass substrate, fitted with a plastic cladding sheet and vacuum conformally sealed. The solar cell modules are tested for electrical performance, framed and inspected. The completed solar cell modules are packed for shipment.

Figure 1

SENSOR TECHNOLOGY, INC.
Array Automated Assembly Production Flow

B. Process Group Summaries

The automated process sequence is being investigated in seventeen groups. The process groups are listed as follows:

1. Cell Test Data Acquisition
 2. Plasma Etching of Resist
 3. Laser Trimming & Holing Operation
 4. Wafer Surface Preparation
 5. Laser Scanning Inspection
 6. Wafer Printing
 7. Low Pressure Vapor Metal Deposition
 8. Silicon Nitride A.R.Coating
 9. Wafer Plating
 10. Solder Coating and Flux Removal
 11. Cell Handling for Module Construction
 12. Laser Trimming & Holing Automation Study
 13. Cell Test & Data Storage Automation & Module Test Study
 14. Module Construction Study
 15. Spray on Dopants
 16. Conveyorized Dopant Diffusion
 17. Module Model Fabrication & Materials
- A. Reports
 - B. SAMICS

Analysis of each process step will be performed in one of these groups. Reports will be made on the analysis. A SAMICS report will be made after our analysis of each process group is complete. Data was gathered and analysis begun for four process groups during this quarter. They are discussed below.

1. Cell Test Data Acquisition

Sensor Technology is presently using a solar cell module test data acquisition system to record the electrical performance under a pulsed Xenon sampling simulator for production contracts. This system automatically plots the I-V characteristic curve on an X-Y plotter.

A design modification to our electronic equipment has been made which will demonstrate that a single solar cell can be automatically tested and its electrical performance recorded. A sketch of the experimental apparatus for the automatic cell test data acquisition system is shown in Figure 2. The complete system consists of a pulsed Xenon light tower; a temperature controlled solar cell mounting block with reference cell; an automatic cell test data acquisition system for measuring short circuit current (I_{sc}), open circuit voltage (V_{oc}), current

Figure 2. Sketch of experimental apparatus for the automatic cell test data acquisition system.

at a predetermined fixed voltage (I_v), cell current (I_{cell}) and cell voltage (V_{cell}) and an X-Y plotter for recording the solar cell electrical performance. This system is designed for computer interface for data storage and for adaptation to solar cell module electrical performance.

2. Wafer Surface Preparation

This process group prepares the silicon wafers for the doping process. Within the scope of this contract an existing surface macrostructure etch sink and cascade rinse system, as shown in Figure 3, is being used for the automation analysis. It produces texturized silicon wafers which have black antireflection surfaces, which have uniform texturized surfaces, and which are reproducible from batch to batch.

The present surface preparation process equipment was modified to process a sample volume of silicon wafers. Carrier baskets were designed and fabricated to carry standardized jigs. The baskets can carry four jigs or 100 silicon wafers. Spin rinse/dryer buckets were procured. The surface macrostructure process has a capacity of 700 silicon wafers per cycle. The silicon wafers are manually stepped through the process from texturization, to clean and rinse, and dry. The drying process includes a study of blow drying as well as spin drying. The surface macrostructure process equipment is now ready to process 90 mm diameter silicon wafers in sample volume for a projected automated process analysis.

Figure 3. Sketch of experimental surface macrostructure process equipment.

3. Laser Trimming and Holing Operation

The laser trimming and holing operation was defined. A laserscribe computer program for sequentially trimming a hexagon and cutting a central hole from a round silicon wafer is being negotiated for procurement. Programming of Quantronix Corporation's Model 603 Laserscribe with a logic board and study of a laserscribe system for higher throughput will be made. A software flow chart and operating procedures outline for a combined hexagon and central hole program will be written. A chuck with a circular moat for central holes from 0.1" to 0.5" diameter will be fabricated. A logic board for storing the hexagon and central hole programs will be fabricated. An automation study will be made.

Laserscribe model 603 as shown in Figure 4 was used in JPL Contract 954605 to cut hexagonal solar cells. It was found in that program for the development of low-cost, high energy-per-unit-area solar cell modules that the laserscribe can reduce junction current leakage losses by trimming the edge of solar cells; it can cut through the p-n junction without damaging the junction; and that the junction current leakage caused by edge effects from the laserscribe is uniform, consistent and very small.

Figure 4 . Laserscribe used to cut hexagonal solar cells from circular solar cells. It will be modified to cut hexagonal solar cells with a center hole.

4. Spray on Dopants

This process group explores new technical ground. Equipment will be constructed to develop the processes on an experimental scale. The spray on of n^+ and p^+ dopants in a differential pressure chamber requires significant design and development work. A major effort will be contributed under this contract to develop a prototype system. On the scale of this contract we intend to develop a chamber with a quartz boat that can be inserted in the slot at one end and pulled out manually at the other. The pulling can also be effected by automatic boat pullers which simulate the conveyor action and determine the lateral speed of the wafer spray nozzles. Differential pressure will be effected by pumping systems and the length of the differential chamber will be determined by the amount of and type of pressure required.

It is through the equipment to be constructed that Sensor Technology intends to demonstrate the feasibility of such a process. The effect of automation on this process will also be studied and reported. The dopant drive in process will be demonstrated on the scale of this contract in an open ended tube by introducing the wafers on a boat and pushing in and pulling out with a manual boat puller. This will help to evaluate the pulling speed. The shape of the furnace and the conveyorized system will be simulated in the differential pressure chamber process.

The demonstration of the excess dopant removal process will involve removing an oxide while the wafers are on a quartz boat, with depth of solution and the speed of the conveyor as the parameters.

The effect of automation on this step is the automatic and sequential transfer by conveyor or jigs in their respective solutions which will enable a systematic feed through. We will build prototype tanks for the basic process and design on paper the automated machine which we think would effectively do the job, based on parameters which we obtain in the prototype experiments.

Information on the spray on dopant process is being gathered. Companies who are specialists in the spray on dopant field are being contacted to determine the best process procedures. Spin-on equipment is being used to test the viscosity, thickness of application, and concentration of several dopants for use in the spray on dopant process.

III. CONCLUSIONS

The work performed on Phase 2 of the Array Automated Assembly Program during this quarter has led to two conclusions. The data acquisition system design indicates that this automated process step will be very useful in the analysis of solar cell electrical performance, and it is a technique suitable for large scale production. The surface macrostructure process equipment has a capacity of 700 wafers per cycle and is presently suitable for large scale production.

IV. RECOMMENDATIONS

The program is on schedule, and it is recommended that no changes be made in the program plan shown in Figure 5 .

V. NEW TECHNOLOGY

No new technology has been developed to completion for this quarterly report.

VI. PROGRESS SUMMARY AND PROGRAM PLAN

The progress summary and program plan for Phase 2 of the Array Automated Assembly Task is shown in Figure 5.

The program for the next quarter is outlined as follows:

1. A cell test data acquisition system will be fabricated. It will automatically record the electrical performance of solar cells. A SAMICS report on the projected 1986 goals for this process step will be written.
2. Plasma etching of resist will be investigated and the results reported. A SAMICS report on the 1986 goals for this process step will be written
3. Programming of laserscribe with a logic board and study of a laserscribe system for higher throughput will be made. A software flow chart and operating procedures outline for a combined hexagon and central hole program will be written. A chuck with a circular moat for central holes from 0.1" to 0.5" diameter will be fabricated. A logic board for storing the hexagon and central hole programs will be fabricated.

4. Silicon wafer surface preparation experiments will be performed and results projected in the automation study. A SAMICS report on the projected 1986 goals for this process group will be written.
5. Laser scanning inspection system specialists will be contacted and an analysis made for the projected automation goals.
6. Information on automated equipment for printing silicon wafers will be gathered and system analysis will be started.
7. Low pressure vapor metal deposition equipment will be investigated for experimental use.
8. Silicon nitride antireflective coating equipment will be rented for experimentation.
9. Wafer plating equipment will be studied.
10. Solder coating and flux removal equipment will be studied.

11. Literature on solar cell wafer handling equipment will be gathered.
12. Laser trimming and holing automation study will not be made this quarter.
13. Cell and module test data storage analysis will not be made during this quarter.
14. A module construction study will begin during this quarter. A printed circuit sheet will be designed. Information on automated assembly equipment will be gathered. Information on encapsulation systems will be studied.
15. Preliminary spray on dopant experiments will be performed with the results used to design test equipment. Spray on dopant equipment will be designed and fabrication will be started.
16. A conveyORIZED dopant diffusion study will not be made during this quarter.

17. Work on the module model fabrication procedure will be begun this quarter.

Figure 5 . Phase 2 Array Automated Assembly Task
Progress Summary and Program Plan

△ planned goals
▲ completed goals

VII. LIST OF DEFINITIONS

The following terms are defined as used in reports on this automated process program:

Automatic Cell Test Data Acquisition Systems - equipment

that automatically records the electrical performance i.e. I_{sc} , V_{oc} , I_v , I_{cell} , V_{cell} , of a solar cell under a solar simulator.

X-Y Sampler - equipment to sample a predetermined point,

i.e. at 100 mW/cm^2 , on a pulse of light. It is designed to work under Sensor Technology's proprietary Xenon pulsed sampling simulator.

Surface Macrostructure - the surface structure resulting

from differential etching along the silicon crystal planes, so that radiant energy will be absorbed more efficiently. A surface macrostructure is also a texturized surface.

Scribe - to partially cut by laser into a silicon wafer
in preparation for breaking.

Trim or Cut by Laser - to sequentially scribe and break
silicon wafer.

Laserscribe - a machine which has a focused laser beam
and a computer for controlling the position and
velocity of a moveable platform carrying the
silicon wafer for trimming and holing.