SOLAREX

DEVELOPMENT OF AN IMPROVED HIGH EFFICIENCY THIN SILICON SOLAR CELL

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BY

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TECHNICAL CONTENT STATEMENT

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I. ABSTRACT

Efforts in this quarter were concerned with optimizing techniques for thinning silicon slices in NaOH etches, initial investigations of surface texturing, variation of furnace treatments to improve cell efficiency, initial efforts on optimization of gridline and cell sizes and Pilot Line fabrication of quantities of 2cm x 2cm 50 micron thick cells. Deliveries of both experimental samples and Pilot Line cells were made to JPL.

II. TABLE OF CONTENTS

III. SUMMARY

This effort is a continuation of work aimed at developing high-efficiency thin silicon solar cells begun in JPL Contract 954290 under the auspices of NASA/OAST. That previous effort resulted in reproducible 50-micron thick solar cells of approximately 11% AM0 efficiency, and Pilot Line fabrication of such cells. This new program continues efficiency improvement and Pilot Line fabrication of improved ultra-thin cells. Experimental 2cm x 2cm cells fabricated in this quarter have now exceeded 12.8% efficiency and are approaching 13% AM0 efficiency.

Tasks on optimizing thinning techniques, surface texturing to improve optical coupling and optimizing cell size were implemented. In addition, Pilot Line fabrication was restarted and 1000 cells from the Pilot Line Fabrication task were delivered to JPL along with experimental samples.

IV. TECHNICAL DISCUSSION

A. Optimization of Thinning Process

During the previous contract a breakthrough in thinning success was achieved with the discovery that as-sawn slices with (100)-oriented surfaces could be etched in hot NaOH solutions down to thicknesses of tens of microns without selective perforations or thin areas, but rather with essentially plane, parallel surfaces having only a slightly "pillowed" surface microstructure. The resulting ultra-thin slices were found to be extremely flexible and resilient, being quite amenable to near-standard fabrication handling.

During this first quarter of the new effort the parameters involved in the chemical thinning process were re-examined to determine the optimum conditions for slice thinning. It was determined that the thinning process is quite forgiving and as non-critical as first believed in the previous effort. Concentrations of NaOH in water ranging from 17% to 40% by weight produce essentially identical results if the etchant is maintained at 105°C or higher temperature. The lower concentration is more economical of materials and produces equally good surfaces and thickness, with excellent control. Below 100°C the etch begins to produce square flat-bottomed preferential indentations in the (100) slice surface, but this deviation from full-surface planarity disappears completely for etchant temperatures over 105°C. Temporary cooling of the etchant bath when room-temperature slices are introduced in quantity is not deleterious when the bath is kept near 110°C and the incidence of any square-feature indentations then disappears. Other than these easily managed considerations no changes other than moderate etch rate alterations were found over the wide range of NaOH concentrations. Consequently, a bath of 18% by weight NaOH solution at 110°C is now being employed for thinning.

Cleaning to remove sodium silicate etching residues consists of HCl diluted 1:1 with deionized water. The slices are immersed in this solution for two (2) minutes after a tap-water rinse to remove the majority of the NaOH left on the slices from the etch bath.

B. Efficiency Improvement -- High Temperature Treatment

From considerations of the interactive effects previously studied in junction formation and back surface p^+ formation it was decided to experiment further with the possible stress conditions occurring during high-temperature processing.

These ultra-thin slices tend to bow of their own weight when not lying on a horizontal surface. One variable not investigated to any extent previously is purposely flexing the slices during high-temperature treatment to stress the silicon lattice. To this end, slices were placed in quartz boats which had slice-holding slots cut at 45° from the vertical. Diffusion of slices with phosphine was then performed with half of the slices bowed (by their own weight) so that their front surfaces were convex during diffusion and the other half of the slices in the experimental groups had their front surfaces concave during the diffusion. The results of these experiments are summarized in Table I for the completed cells (without coverslide filtering).

TABLE I

CONCAVE-CONVEX DIFFUSIONS

PARAMETER	AVERAGE VALUES	
	CONVEX FRONT	CONCAVE FRONT
I_{sc} (mA)	145	135
I_{sc} blue (mA)	44	40
I_{sc} red (mA)	73	68
V_{oc} (mV)	574	568
P_{max} (mW)	65	59

These slices had smooth surfaces (no texturing) and were diffused at 840°C, yielding a sheet resistance of 115 to 135 ohms per square. They had 8000Å of aluminum evaporated on their backs and alloyed at 840°C with the same direction of curvature as for diffusion. It is quite apparent from Table 1 that a significant improvement in cell efficiency is obtained with the cells flexed to make the fronts convex during high temperature processing, as opposed to having the fronts concave. It is to be noted that both the currents and voltages increased with the convex fronts. It is quite apparent that there is a strong interaction between slice stresses at high temperatures and resultant solar cell properties. This area will be pursued further in the coming quarter, but has already produced a significant jump in cell efficiencies.

C. Optimization of Dimensions for Cost

During this quarter design of artwork and masks for larger cells commenced. To date, all of the deliverable ultrathin cells have been 2cm x 2cm in size, but much larger cells 50 microns in thickness have been fabricated experimentally although with coarser gridline patterns normally employed for terrestrial cells. In order to improve the eventual productivity for ultrathin cells, they too should be fabricated in sizes considerably larger than 2cm x 2cm. In this contractual effort at least 200 large ultrathin cells will be delivered at the end of the next quarter to familiarize the photovoltaic community with handling and interconnection of such cells. Consequently a task was begun in this quarter to design a high-efficiency large ultrathin cell for space applications.

A semi-universal design with a gridline field covering up to 6cm x 6cm of possible cell area was generated. It could be employed for cells of 2cm x 4cm, 2cm x 6cm, 4cm x 4cm, 5cm x 5cm, or up to 4cm x 6cm in size. It employs the same fine-line chevron geometry as used for the 2cm x 2cm cells and should produce comparable cell efficiencies from a shadowing and series resistance standpoint. Both the design task and cell fabrication/evaluation will be completed in the coming quarter.

A wider-gridline terrestrial cell similar in design to those to be fabricated in this effort is shown in Figure 1 in a 5cm x 5cm size. A study will be made in the coming quarter to determine which of the possible sizes would be most advantageous for space application of ultrathin cells from the standpoint of overall processing yield and cost.

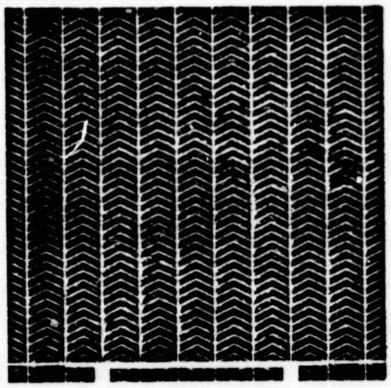

Figure 1. 5cm x 5cm Solar Cell

D. Pilot Line for Ultrathin Cells

During this quarter the Pilot Line which was set up to produce ultrathin cells under the previous contract was reactivated. The etching station set up under the original Pilot Line operation was in need of repair due to some original hasty construction details producing structural corrosion by the NaOH, but the other apparatus is in essentially perfect condition. Solarex is adding an additional evaporator for anti-reflective coating (donated by Solarex for use in the Pilot Line project) to eliminate a capacity bottleneck for increased output of cells.

The first lot of slices fabricated into 50 micron cells by the Pilot Line only resulted in a 13% overall processing yield, which reflected the training period for new operators, but the last lot in the first month reached an overall yield of 42%. These first lots also did not have tantalum oxide antireflection coatings applied (at JPL's request, for studies of other covering materials). and were therefore not directly comparable to the lots fabricated in the previous effort. However this quick recovery to reasonable processing yields was very encouraging.

During the remainder of the quarter the lots fabricated by the Pilot Line employed process conditions which were updated in conformance with the results of the parallel experimental efforts, while the first few lots employed essentially the same conditions as in the previous effort. Utilization of the convex-front configuration during high-temperature processing confirmed the results of the experimentation efforts in raising cell efficiencies to levels above 12% at AM0, although with some scatter.

Characteristic curves representative of the improvement produced by having Pilot Line slice fronts convex during high-temperature processing are shown in Figure 2 and Figure 3. It can be seen from the two plots that both the short circuit current and the open circuit voltage are improved by performing high-temperature processing with the slice fronts flexing to convex. These I-V curves were measured for cells without final coverslide filtering and would show higher currents if so covered.

Some of the cells shipped to JPL had magnesium flouride applied over their tantalum oxide coatings to demonstrate that 68-70mW can be achieved in the final filtered form of cell assemblies, as compared to uncovered cells. (28 cells were so coated.)

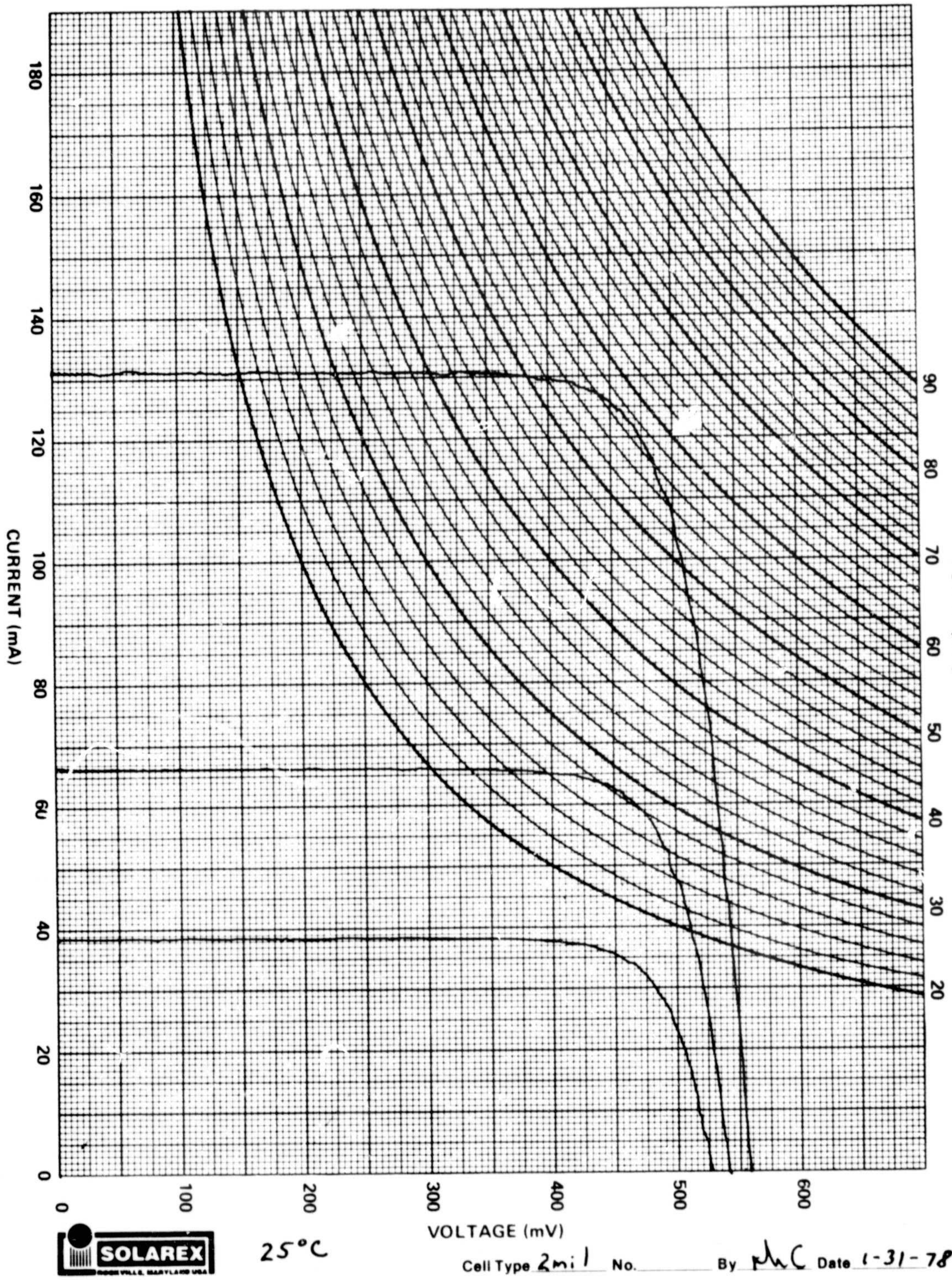

Figure 2. AM0 I-V curve for a 50 micron 2cm x 2cm cell not purposely flexed during high-temperature processing.

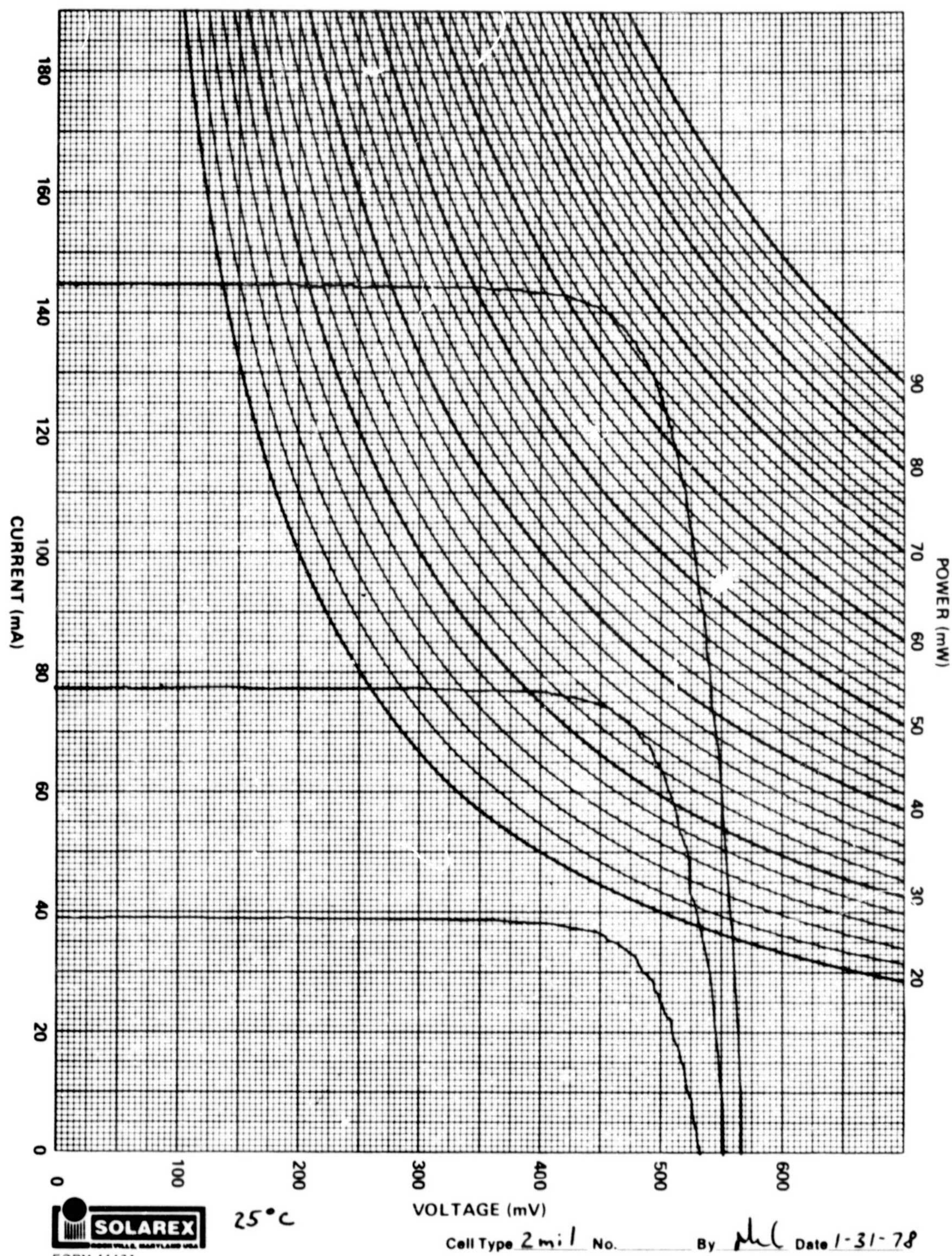

Figure 3. AM0 I-V curve for a 50 micron 2cm x 2cm cell with its front convex during high-temperature processing.

V. CONCLUSIONS

1. Etching parameters for slice thinning are very tolerant of etchant concentration and temperatures for operation in excess of 105°C. An 18% by weight NaOH solution is quite sufficient for controlled, economic operation.

2. High temperature treatment with the cell fronts flexed to a convex shape has increased cell efficiencies to the 12%-13% range.

3. The Pilot Line effort has restarted with reasonable processing yields.