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DEVELOPMENT OF AN IMPROVED HIGH EFFICIENCY THIN SILICON SOLAR CELL

JPL CONTRACT NO. 954883

JULY 1979

SEVENTH QUARTERLY REPORT

REPORT NO. SX/115/7Q

BY

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TECHNICAL CONTENT STATEMENT

This report contains information prepared by Solarex Corporation under JPL subcontract. Its content is not necessarily endorsed by the Jet Propulsion Laboratory, California Institute of Technology, or the National Aeronautics and Space Administration.

ABSTRACT

Breakage and front contact failure in high efficiency, textured ultrathin cells has been reduced as a consequence of the introduction of process modifications. In a small production run, over one hundred ultrathin cells having an average AMO efficiency of 13% were fabricated from 10-25 ohm cm silicon. An in-house aluminum paste for back surface field formation was developed that resulted in cell efficiencies equivalent to those from commercial pastes. The quality of the back surface field was found to be dependent on the orientation of the silicon slice during alloying.

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III. SUMMARY

The principal goals of the work performed under this contract are to do the necessary research work that will lead to pilot line production of high efficiency ultrathin cells and the pilot line production of 2000 2 cm x 2 cm cells and 1000 5 cm x 5 cm cells. During the past quarter, yield problems associated with breakage and front contact failure were investigated. As a consequence, modifications at particular process stages have resulted in increased yields at those stages. A small production run was initiated that resulted in 118 textured 2cm x 2cm cells having an average AMO efficiency of 13% (28^{o}c). Process stages requiring further improvement with respect to yield were identified in this production run. High efficiency (up to 12.2% AMO) 25 CM^2 textured ultrathin cells were fabricated with reasonable process yields. An in-house aluminum paste was prepared that gave the same results as a commercial formulation. Finally, silicon slice orientation during aluminum paste alloy was investigated and an effective orientation was determined.

IV. TECHNICAL DISCUSSION

A. Process yield of 4 cm^2 cells - Past experience with planar and textured ultra thin cells has demonstrated that yields are considerably reduced either by breakage or by front contact failure. In the present phase of the contract, considerable effort is being directed towards solving these problems in preparation for pilot line production runs of both 2 cm x 2 cm and 5 cm x 5 cm ultrathin cells. A number of changes have been instituted in the process sequence to reduce these problems.

The basic process sequence is shown in figure 1. Breakage of the wafers occurs throughout the processing. In the photolithography step necessary for contact formation, breakage often occurred when resist is spun onto the silicon slices. Lumps of regrown silicon produced by the alloying of the aluminun paste provide stress points when the slices are held down by the spinner vacuum chuck. By cushioning the wafers and controlling the pattern by which the slices are held to the chuck by the vacuum, breakage was effectively eliminated.

Plating also presented a breakage problem because the racks were not well suited to thin cell fabrication. A redesign of the racks increased yields through this process step.

The other major problem area has been the contact formation process. Poor adhesion and grid interrupts have often resulted from problems that have arisen in contact formation.

Figure 1

Process Sequence for 2 cm x 2 cm cells

WAFER
(10-15 Ω-cm)

THINNING ETCH
(NaOH)

TEXTURE ETCH
(KOH-Isopropanol)

PHOSPHORUS DIFFUSION
(860^{o}C for 15 min)

ALUMINUM PASTE ALLOY
(850^{o}C)

CONTACT FORMATION
(Ti-Pd-Ag)

ANTI-REFLECTION COATING
(TaOx)

CELL

Two minor changes in the process sequence have been introduced that have apparently reduced front surface grid failures significantly. One of these changes involves the omission of an HF etch after pattern development and prior to metallization. It is thought that incomplete rinsing of the HF allowed for the evaporated metals (Ti, Pd) to be attacked, the problem being more severe with textured surfaces. The other change involves the introduction of a low temperature (150^{o}c) heat treatment for 20 minutes after Ti-Pd evaporation and prior to Ag deposition. This process is thought to cause a tighter binding between the titanium and silicon, thereby enabling the total contact system to withstand stresses caused by subsequent higher temperatures sintering treatments.

As of now, the data base on which the effectiveness of the above procedures is being judged is small. Further work is continuing to obtain more data on the critical factors affecting contact integrity.

Subsequent to this work, a small production run was begun to provide the cell deliverables for the current quarter. Yields at the different processing stages were monitored and recorded. A total of 504 potential textured ultrathin cells were started. One hundred eighteen (23.4%) fabricated from 10-25 Ω cm silicon were completed with acceptable electrical characteristics and visual appearance.

One hundred of these cells were delivered to JPL with an average AMO efficiency at 28°C of 13%. Table 1 indicates those areas at which the yields were significantly affected. Breakage accounted for the loss of 198 cells, or 39% of the cell starts. Major breakage occurred in the Al paste silk screening step (10.7%) and in the clean-up after Al alloying (9.5%). Front contact failures accounted for the loss of 147 cells, or 29% of the starts. Twenty-seven cells (5%) had pinholes in them due to alloying of the aluminum completely through the silicon. Fourteen cells (2.8%) were rejected because of low output power.

Most front contact failures were due to a faulty metal evaporation, and therefore, is readily correctable. Breakage at the silk screening stage is expected to diminish with operator experience. New clean up procedures after alloying have since been instituted, and breakage has been significantly reduced. This has involved using a more concentrated HCl solution for initial residue removal and diminishing the time spent in the ultrasonic water bath.

Small production runs are planned for the future using the modified procedures. Yields at the different process stages will be monitored as was the case for the production run reported above.

TABLE 1

Ultra-thin Cell Yields

Process Step	Broken	Front Contact Failures	Pinholes in Cells	Electrical Rejects
1. Diffusion	6			
2. Paste Screening	54			
3. Alloy	48		27	
4. Front Contact Formation	54	147		
5. Back Contact Formation	24			
6. Edge Cleaning	7			
7. Test	5			14
Total Rejects	198	147	27	14

Figure 2

Process Sequence for 5 cm x 5 cm cells

WAFER
(10-15 Ω-cm)

THINNING ETCH
(NaOH)

OXIDE FORMATION

PATTERN FORMATION VIA PHOTOLITHOGRAPHY

TEXTURE ETCH
(KOH-Isopropanol)

PHOSPHORUS DIFFUSION
($860^{\circ}C$ for 15 min.)

ALUMINUM PASTE ALLOY
($850^{\circ}C$)

CONTACT FORMATION
(Ti-Pd-Ag)

ANTI-REFLECTION COATING
(TaOx)

CELL

B. 5 cm x 5 cm cell fabrication - A number of silicon slices were processed into 5 cm x 5 cm x 0.05 mm textured solar cells during the previous quarter in order to gain experience for pilot line production runs. The process sequence was modified so that the silicon slices could be handled with fewer losses due to breakage.

This entailed etching the wafers to a thickness of 0.09 mm and then texture etching a 5 cm x 5 cm area to a thickness of 0.05-0.07 mm. The contact pad area was left untextured using photo lithography. The details of the sequence are seen in figure 2.

Seven of twenty five potential cells were completed. The output characteristics are seen in Table 2. The best cell had an AMO efficiency of 12.2% at 25°C. Some non-uniformity in the current density (up to 10%) produced by different parts of the cells was measured. These non-uniformities are being investigated. Open circuit voltages indicate that reasonably effective back surface fields were formed over the entire cell area.

C. Aluminum paste formulation - Because of the substantial cost of commercial aluminum pastes, an effort was undertaken to prepare an aluminum paste from the basic materials. This effort was successful, as can be seen in

TABLE 2

AMO Output Characteristics of 5 cm x 5 cm Ultrathin Cells

Cell #	Isc(mA)	Voc(V)	Pm(mW)	(%)
1	880	580	400	11.8
2	930	572	410	12.2
3	890	515	360	10.6
4	900	575	390	11.5
5	920	572	400	11.8
6	950	557	390	11.5
7	930	565	325	9.6

TABLE 3

Comparison of Open Circuit Voltages from Commercial And In-House AL Paste Formulations

Paste	#of Cells	$\overline{\text{Voc}}$ (mV)	min Voc (mV)	max Voc (mV)
Englehard A-3484	33	570	547	597
In-House	40	570	551	601

Table 3. Little difference in the open circuit voltage was measured when comparing Englehard paste #A-3484 and the in-house formulation. The formulation consisted of fine aluminum powder, terpineol, ethyl cellulose and butyl carbitol.

D. Silicon slice orientation during Al alloy - Stress and temperature gradients during alloying of the aluminum pastes appear to affect significantly the open circuit voltage and power of thin cells. Investigations have continued whose aim is to determine the effect of the silicon slice orientation during alloying. In one such investigation, silicon slices were alloyed either with the paste side facing up or down, with the slice being flat on a boat in an alloy tube furnace. The results are seen in Table 4. Clearly, better results were obtained when the paste screened side was facing upwards during the alloy.

As a consequence of this and previous experiments, it appears that the best results can be obtained by orienting the silicon slices flat with paste side up using a belt furnace with a temperature profile that allows for a rapid heat-up and a slower cool-down of the silicon slices.

TABLE 4

Effect of Silicon Slice Orientation During AL Alloy
On The Open Circuit Voltage

Orientation	#of Cells	$\overline{V_{oc}}$ (mV)	min V_{oc} (mV)	max V_{oc} (mV)
1. Slice Flat, Paste Side Up	14	578	551	591
2. Slice Flat, Paste Side Down	20	568	533	580

V. CONCLUSIONS

1. High efficiency (13% AMO), textured, aluminum-paste alloyed, ultrathin cells can now be readily fabricated. Yields can be increased by appropriate modification of critical process steps.
2. High efficiency 25 cm^2 cells can be fabricated with reasonable process yield.
3. Aluminum pastes that result in cell power outputs equivalent to those produced by commercial pastes can be easily prepared.
4. Silicon slices alloyed with the aluminum paste side facing upwards will produce cells with high performance characteristics.

PROJECTED ACTIVITIES

The emphasis of the program will be to do the necessary research work that will lead to the pilot line production of high efficiency 2 cm x 2 cm (2000 cells) and 5 cm x 5 cm (1000 cells) ultrathin cells. Technology developed during the research phase will be transferred to the pilot line production efforts. This will specifically include texturing of the silicon cells and using aluminum pastes for back surface field formation. In addition, efforts will be undertaken to address those processes that are responsible for losses in cell yields. These include wet processing steps that cause silicon slice breakage and the contact formation steps. Finally, a measurement and analysis program will be undertaken in order to determine the quality of back surface fields and the limiting factors on the open circuit voltage.

In the near term (3 months), work will continue on contact integrity problems and problems associated with some aspects of the wet processing (particularly silver plating). Also, interrupted back contacts for stress relief will be investigated on both 2 cm x 2 cm and 5 cm x 5 cm cells. One hundred 2 cm x 2 cm cells will be fabricated for delivery at the end of September. Also a number of 5 cm x 5 cm cells will be fabricated.

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