THIN CELLS FOR SPACE*

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ABSTRACT

Research and pilot line production efforts directed towards the fabrication of high efficiency ultrathin silicon solar cells (50 um) are reported. The research efforts have resulted in conventional ultrathin cells with AMO efficiencies exceeding 14% and coplanar back contact cells with AMO efficiencies up to 11.7%. The primary mechanisms limiting efficiency have been determined in both types of cells, and they are discussed within the context of further improving efficiency. Results of pilot line production of conventional ultrathin cells are also presented. Average AMO efficiencies of 12% have been readily achieved for 2000-cell production runs.

INTRODUCTION

A significant advance in silicon solar cell technology for space applications has been the fabrication of high efficiency ultrathin (50 μm) cells that are nearly independent of base resistivity (Ref.1,2). This includes the conventional ultrathin cell which incorporates a high-low $p^+ - p$ junction at the rear of the cell and the coplanar back contact cell which has high-low $p^+ - p$ junctions both on the front and on certain regions at the back of the cell. As a consequence of the new technology, the power to mass ratio has increased dramatically over that of conventional, 200 μm thick space cells. In addition, conventional ultrathin cells have been found to be particularly resistant to radiation damage because the distance that the minority carrier must travel to the collecting junction is relatively short.

No less important have been the breakthroughs in manufacturing technology that have resulted in highly producible conventional ultrathin cells (Ref. 3). Solarex has fabricated several thousand of this type of cell.

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In this paper, we present results of research efforts on both the conventional and coplanar back contact cells and of the pilot line production efforts on the conventional cells. Also, we discuss the principal loss mechanisms affecting cell efficiency in both types of cells.

RESEARCH EFFORTS

a. Conventional Ultrathin Cells - The basic processing sequence is seen in Figure 1. Silicon wafers are thinned down and textured using NaOH and KOH-isopropanol etches, respectively. The slices are then diffused at 860°C using PH_3 as the diffusant source. Aluminum paste is then silk screened on one side, cured at 90°C for one-half hour and fired at 850°C for approximately thirty seconds. After cleaning up the alloy residue, standard Ti-Pd-Ag contacts and a Ta_2O_5 AR coating are deposited on the cells. Using this process technique, cells having AMO efficiencies greater than 13% at AMO are consistently obtained. Figure 2 shows the I-V characteristics of the best of these cells (η = 14.1% at 25°C). For comparison purposes, the I-V curve of a non-textured thin cell which had evaporated aluminum as a source for back surface field formation is shown. As can be seen in the figure, texturing in a junction with an effective back surface field produces a significant increase in current because of a reduction in reflection and the generation of minority carriers closer to the junction.

This is further seen in Figure 3, where the spectral response of the two cells is shown. The major difference in the two curves is the reflection, although at long wavelengths ($\lambda > .85$ µm) there is additional current collection because of the refraction of the entrant light.

Textured cells having open circuit voltages greater than 600 mV have been fabricated when Al pastes have been the source for back surface field formation. This is considerably better than the open circuit voltages obtained when evaporated Al is used as the source. At present, the material processes responsible for the difference are not known.

b. Coplanar Back Contact Cell - In another program, Solarex has been fabricating coplanar back contact cells - that is, cells in which the contacts to both the n^+ and p^+ regions are located on the back of the cells. The motivation for the development of this type of cell is the high cost associated with solar cell assembly.

The process sequence for this cell is seen in Figure 4. After thinning with a NaOH etch, a boron doped silicon dioxide layer is deposited on the front of the slice and an un-doped oxide layer on the back. In a series of photolithography steps, portions of the back oxide are removed for phosphorus diffusion and high-low p^+ - p junction formation with evaporated Al as the source. The resultant n^+ and p^+ regions are then metallized with Ti-Pd-Ag to provide contacts to the cell. The front oxide is then removed and a Ta_2O_5 anti-reflection coating applied.

Figure 5 shows the basic pattern of the n^+, -p, and p^+ regions at the back of the cells. With a step and repeat of 20 mils, the n^+ region is 16 mils wide and the p^+ region 2 mils wide. The two regions are separated by p-regions that are 1-mil in width.

The best cell that has been produced after five months of fabrication effort is seen in Figure 6. The AMO efficiency of this planar cell is 11.7% at 25°C. Resistivity of the base silicon is approximately 5Ω -cm. Current densities are presently limited by less than optimum optical coupling and by low minority carrier diffusion length. A spot scan has shown minima in the current output over the p^+ regions.

The diffusion length in the silicon is a critical parameter for high efficiency coplanar back contact cells. Table I shows the influence of diffusion length on the current density for a 16-1-2-1 mask configuration and for three cell thicknesses. Reflection is assumed to be zero, and the recombination velocities at the p and p^+ surfaces are indicated. Not surprisingly, when the diffusion length decreases to the same order as the cell thickness or the distance between the center of p^+ region and the edge of the n^+ region, the current density is strongly affected.

PILOT LINE FABRICATION EFFORTS

In conjunction with research efforts on conventional ultrathin cells, Solarex has been producing non-textured 50 μm thick cells in a pilot line effort. Several thousand cells have been fabricated. The results of the most recent production runs as seen in Figure 7, representing a total of five thousand cells. The significant increase in output power that occurred during the second quarter was due to controlling cell flexure during high temperature processing. The high power levels seen in some cells during the fourth quarter was to a large extent due to effective back surface fields formed from evaporated aluminum.

In the coming year, pilot line production of textured cells using Al pastes for back surface field formation is planned. A substantial increase in average cell efficiency is expected as a consequence.

LOSS MECHANISMS

The current density and fill factor of the conventional ultrathin cells have been maximized. The open circuit voltage remains at considerably less than theoretically expected values because the emitter recombination current is high. Increased open circuit voltages can be expected with the incorporation of a high-low emitter as has recently been done by Neugroschel, et al. (Ref. 4).

For the coplanar back contact cell with front surface field, better optical coupling and larger minority carrier diffusion lengths are needed to maximize the current density. Fill factors are at satisfactory levels. Open circuit voltages are low for the same reason as with the conventional thin cells. High-low emitter regions should considerably improve the open circuit voltage.

SUMMARY AND CONCLUSIONS

Ultrathin high-efficiency conventional and coplanar back contact cells have been fabricated. Conventional cell efficiencies have exceeded 14%, and coplanar back contact cell efficiencies have reached 11.7%. Non-textured, conventional ultrathin cells have been produced in pilot line quantities. Average efficiencies of these cells have reached 11.6%.

Major increases in efficiency must come by increasing the open circuit voltage of both types of cells. Further work in optimizing optical coupling and maintaining high minority carrier diffusion length is required for high short circuit current densities in coplanar back contact cells.

Thin cells offer substantial advantages with respect to high power to mass ratios. Also, the great flexibility of the cells allows for compact launch configurations of lightweight arrays.

REFERENCES

1. C. F. Gay, "Thin Silicon Solar Cell Performance Characteristics," Proc. 13th IEEE Photovoltaic Specialists Conference, Washington, D.C., 1978.

2. J. Lindmayer, C. Wrigley, and G. Storti, "Development of an Improved High Efficiecy Thin Silicon Solar Cell," JPL Contract No. 954883, Fifth Quarterly Report, January 1979.

3. J. Lindmayer, C. Wrigley, and G. Storti, "Development of a High Efficiency Thin Silicon Solar Cell, JPL Contract No. 954883, Pilot Line Report, November 1978.

4. A.Neugroschel, F. A. Lindholm, S. C. Pao and J. G. Fossum, Appl. Phys. Lett., Vol 33, p. 168, 1978.

TABLE 1. EFFECT OF DIFFUSION LENGTH ON THE SHORT CIRCUIT CURRENT DENSITY OF COPLANAR BACK CONTACT CELLS OF DIFFERENT THICKNESSES

	J_{sc} (mA/cm^2)		
Ln (μm)	t = 50 μm	75 μm	125 μm
1000	42.	43	43
500	42.	43	42
300	42	42	40
200	41	40	35½
150	39½	37½	31
100	36½	32	22
50	25½	17	7

MASK CONFIGURATION: 16 mil - n^+; 1 mil - p; 2 mil - p^+
1 mil - p

ASSUMPTIONS:

1. PLANAR FRONT SURFACE
2. NO REFLECTION
3. $V_s(p)$ = 1000 cm/s
4. $V_s(p^+)$ = 100 cm/S

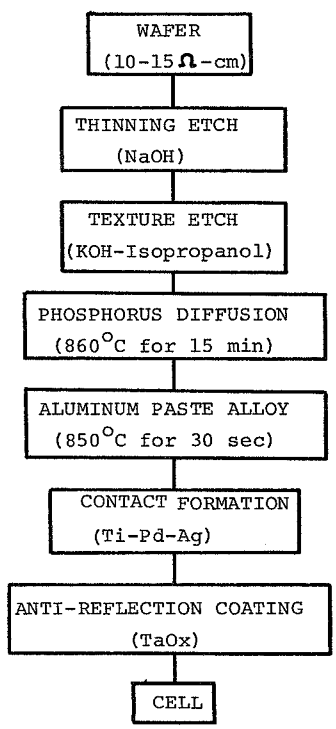


FIGURE 1: PROCESS SEQUENCE FOR CONVENTIONAL, TEXTURED ULTRATHIN CELL

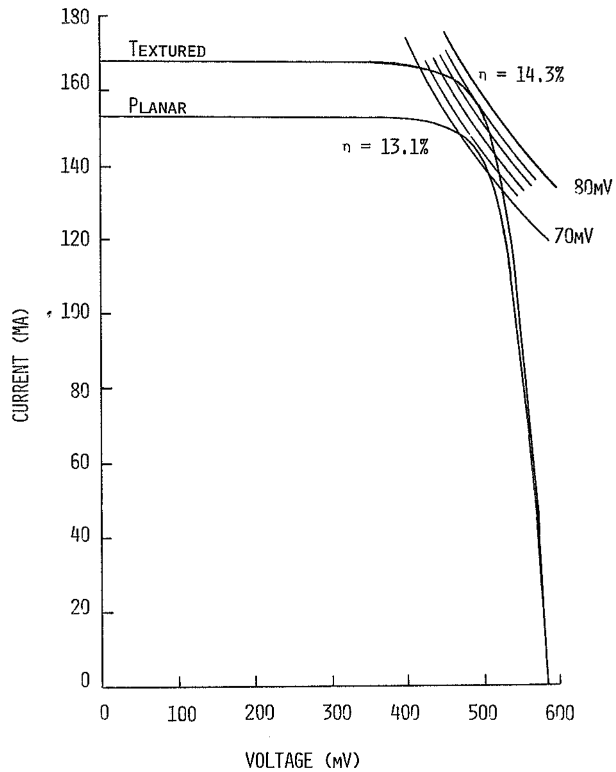


FIGURE 2: I-V CHARACTERISTICS OF PLANAR AND TEXTURED 50μM THICK SILICON CELLS. CELL AREA IS $4 cm^2$.

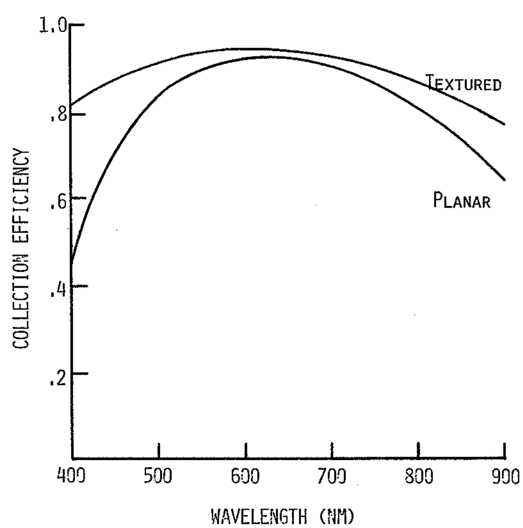


FIGURE 3: SPECTRAL RESPONSE OF PLANAR AND TEXTURED 50μM THICK SILICON CELLS.

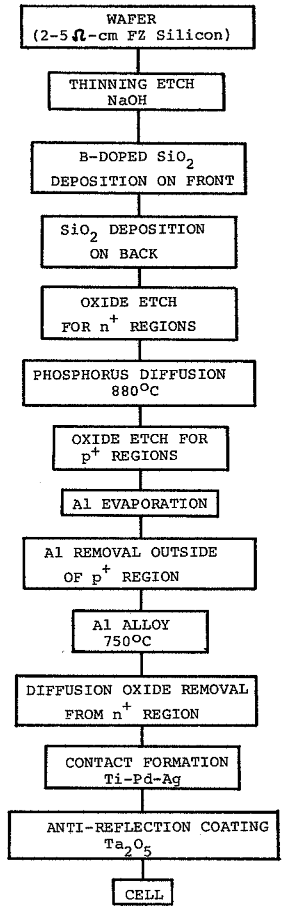
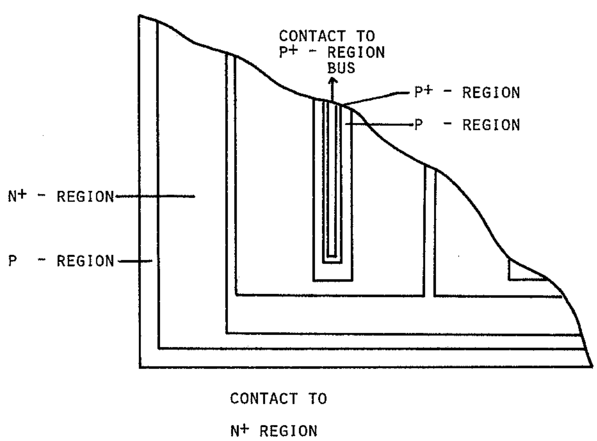


FIGURE 4: PROCESS SEQUENCE FOR THE COPLANAR BACK CONTACT CELL



N+ - REGION WIDTH: 16 MILS (406μM)
P+ - REGION WIDTH: 2 MILS (51μM)
P - REGION WIDTH: 1 MIL (25μM)

FIGURE 5: DIFFUSED REGION AND CONTACT CONFIGURATION OF COPLANAR BACK CONTACT CELL.

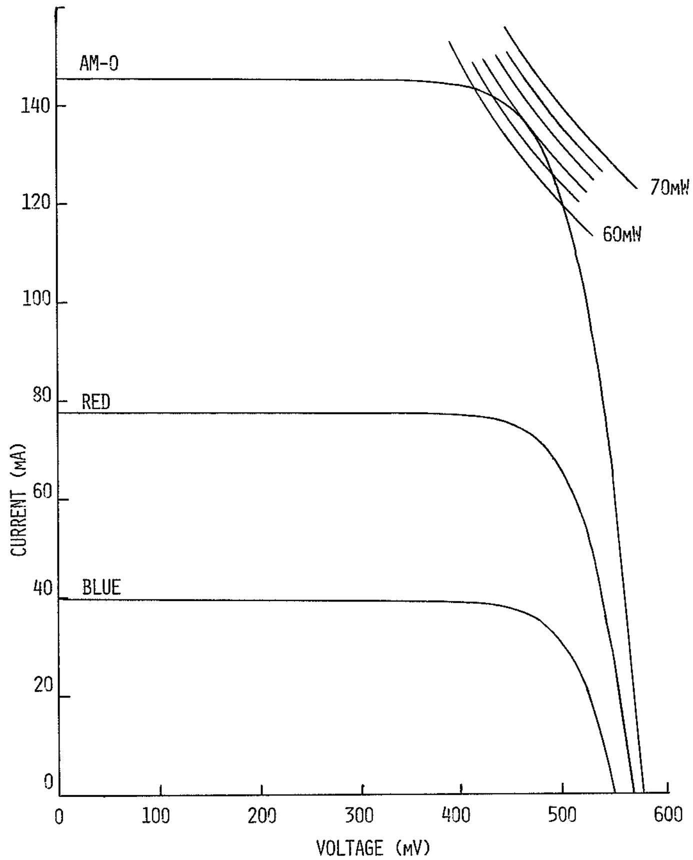


FIGURE 6: I-V CHARACTERISTICS AT 25°C OF THE BEST 50μM THICK COPLANAR BACK CONTACT CELL.

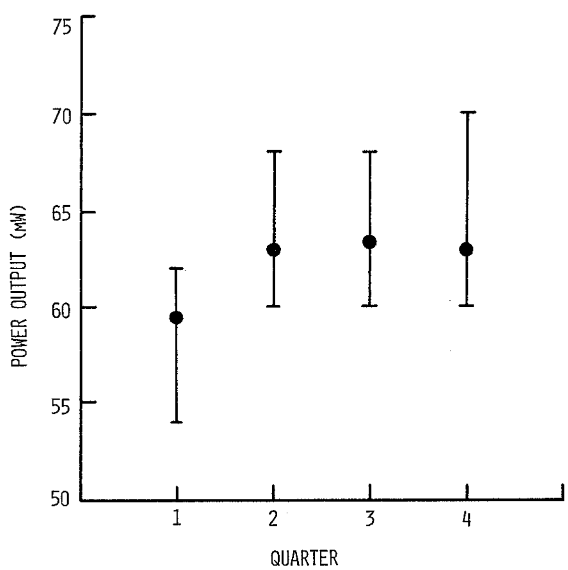


FIGURE 7: AMO POWER OUTPUT AT 25°C AS A FUNCTION OF QUARTERLY PILOT LINE PRODUCTION EFFORTS FOR PLANAR, 50μM THICK SILICON CELLS. CELLS AREA IS 4CM^2