RECENT PROGRESS IN HIGH-OUTPUT-VOLTAGE SILICON SOLAR CELLS*

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High-quality shallow-junction planar solar cells have been fabricated on 0.1 Ω-cm float zone refined silicon using Emulsitone N250 spin-on dopant, aluminum-alloyed back contacts, and "dot" contact front grids (ref. 1). Use of a process similar to the NASA-Lewis double-diffusion process (ref. 2) has reduced shunt leakage and junction recombination currents while adding 10 mV to the best open-circuit voltages obtained from the single-diffusion process.

The present status of a 0.1-Ω-cm covered solar cell (153-mA short-circuit, 654-mV open-circuit voltage, 77.5-mW maximum power, and 14.4-percent AMO efficiency) is characterized in figure 1 before and after covering. The short-circuit current (ISC) is about 6 percent less than that observed in typical higher resistivity ($\gtrsim$1-Ω-cm) violet cells (ref. 3) but the open-circuit voltage (VOC) is about 9 percent higher. During covering or subsequent handling, the cell fill factor was reduced in an unexplained manner (analysis indicates a lowered shunt resistance). If it had been maintained, the maximum power would have exceeded 79.5 mW.

The quantum-yield data are presented in figure 2 along with data from a deeper junction cell ($x_j \simeq 1.6$ μm) from the same batch and a shallow junction ($x_j \simeq 0.1$ μm) cell made by a different process. An important feature of this figure is the unusual shape of the set A curves. A conventional cell with a surface dead layer displays a much more abrupt drop in the short wavelength region rather than the more gentle the slopes observed in figure 2 below 700 nm. It would appear that the double-diffusion process alters the cell characteristics in a manner quite different than expected from a simple change in the diffused layer (see ref. 2 for a possible explanation). Set A had an overnight diffusion with N250 at 880°C followed by different etch times prior to an N250 diffusion at 820°C for 15 minutes; set B was diffused with N250 at 820°C for 15 minutes.

The advantages of a 2-step diffusion process are delineated by comparisons of the data from two sets of cells (table I). The data indicate several differences resulting from a prediffusion; most important are a 10-mV increase in VOC and an improved fill factor of set A. The improved VOC is explained by the lower bulk dark current (JD); the better fill factor (FF) is

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due to the lower preexponential of the n = 2 term (JRC) and higher shunt resistance (RSH). The penalty is reduced ISC and blue response (IB), as seen in figure 2. The long wavelength response ($\lambda \gtrsim 1000$ nm) and the currents (I_γ) from γ-ray irradiation of the two sets are nearly equal and indicate diffusion lengths comparable to or greater than the cell thickness (200 μm). This point is supported by the values of ISC in set B, which are almost as high as those for 1- to 2-Ω-cm violet cells.

Efforts are continuing to better understand the mechanism responsible for increased voltage resulting from the double-diffusion process. Once this mechanism is understood, work can be directed toward further voltage gains and reduction of short-circuit current losses.

REFERENCES

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Table I. UNCOVERED CHARACTERISTICS OF A BATCH OF SINGLY DIFFUSED CELLS (SET B) AND A BATCH OF DOUBLY DIFFUSED CELLS (SET A)

Cell No.	Process	ISC (mA)	VOC (mV)	IB (mA)	F.F.	I_γ [a]	JD (pA)	JRC (nA)	RSH (Ω)
				Set A[b]					
1	N250	130.4	647	29.6	0.82	6.9	0.32	20	365
2	1.6 μm	123.7	642	27.9	0.80	6.8	0.37	32	111
3	N250	133.9	640	33.3	0.80	6.6	0.44	32	1 K
4	~0.9 μm	136.7	646	33.5	0.80	6.7	0.35	31	540
5	N250	142.8	644	37.3	0.80	6.5	0.40	36	1 K
6	~0.3 μm	143.1	646	37.2	0.80	6.6	0.35	43	1 K
7	N250	142.8	648	37.5	080	6.5	0.31	50	1 K
8	~0.15 μm	142.6	650	37.3	0.80	6.2[c]	0.3	39	1 K
				Set B					
1		149.3	629	41	0.73	6.8	0.54	111	46
2	N250	150.8	630	40.8	0.71	7.2	0.54	110	37
3	0.1 μm	150.1	637	40.8	0.77	6.8	0.46	88	134
4		149.2	634	41	0.73	6.4	0.47	97	49

[a] An I_γ of 7.0 corresponds to a diffusion length of ≥180 μm.
[b] Variable etch depth.
[c] Measured with coverslide.

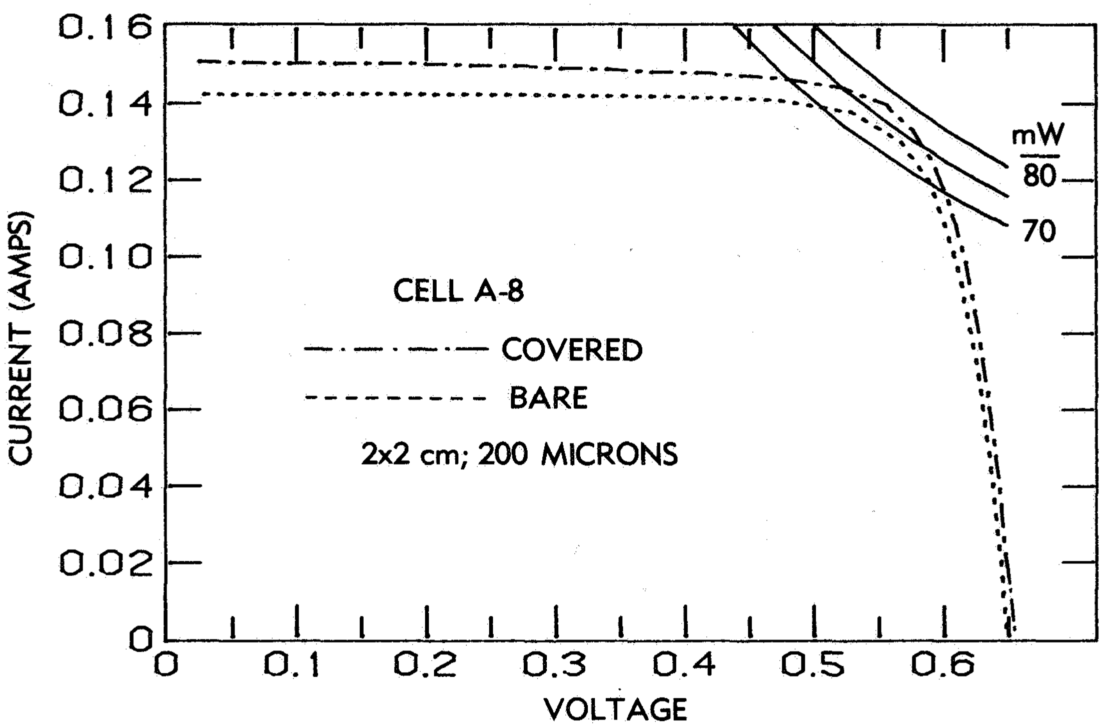

Figure 1. IV Curves for Cell Set A-8 Bare (Dots) and Covered (Broken) Under Simulated AM0 Conditions

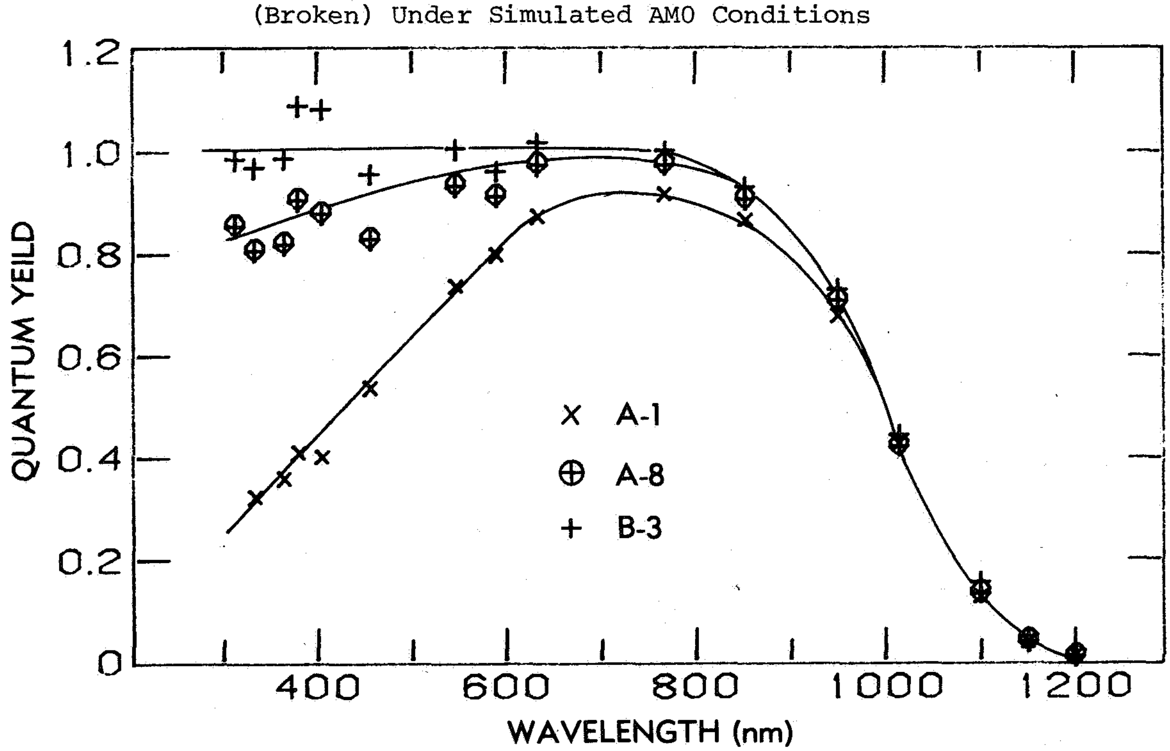

Figure 2. Quantum Yield Results for Cell A-8 ($x_j \cong 0.15$ µm) along with Shallow (B-3) and Deep (A-1) Junction Cells