SILICON SOLAR CELLS FOR SPACE USE: PRESENT PERFORMANCE AND TRENDS

P.A. Iles, F.F. Ho and S. Khemthong
Photoelectronics Corporation of America

FABRICATION METHODS

Much of modern silicon device technology has been applied to make current space cells. This technology includes the use of large single crystals (up to 10 Kg), sliced by advanced ID saws, mechanized polishing methods and cleaning, and diffusion in microprocessor-controlled furnaces. Contacts and coatings are deposited in large evaporators using electron beam-heated sources, and with semi-automatic control of layer properties. Cells are processed through most of this sequence in large slice ($\sim$3") form. The combination of these processes has been shown to retain proven levels of space worthiness and quality control.

BASIC PRODUCTION CELL DESIGN

The surface finish is either polished or textured. The back surface may be of high reflectance (BSR) or include an electric field (BSF). Slice thicknesses are generally 8-12 mils, and resistivities 2-10 ohm-cm are used mostly. The grid pattern designs are determined with aid of computer programs and using photolithographic (or shadow masking) methods, well controlled patterns of narrow, close-spaced lines of high conductance are obtained.

PRESENT PERFORMANCE

AMO Output (Pm)

Values above 21.5 mW/cm^2 ($\sim$16%) have been achieved. For production runs, cells in the range 19-20 mW/cm^2 are specified with increased frequency, although cells in the range 15-17 mW/cm^2 are still required. These output values are those measured at controlled temperatures (25-28°C). Recently, more attention has been paid to the orbital output, determined largely by the value of solar absorptance for the cell.

Solar Absorptance (α_S)

The highest output cells (textured surface) have retained high α_S values (>0.87 even with BSR). Recently significant decrease in α_S (down to 0.72) have been achieved for production non-textured cells with high output, obtained by an effective BSF, and the output of such cells can exceed 95% of that of textured cells. Specially designed cells have had α_S values down to

0.66. The same α_S control has been extended to thin cells ($\sim$2 mils), and in fact the optimum combination of Pm and α_S has been achieved for such cells. Figure 1 shows the Pm (measured at 25°C) versus achieved values of α_S for various production cells. Typical Pm and α_S ranges are indicated. The circles indicate the orbital power output for the Pm and α_S values at the centroid of the dashed rectangle.

Radiation Resistance

The radiation resistance is controlled by the bulk resistivity, and to a lesser extent by the cell design. The resistivity used is between 2 and 10 ohm-cm, where the best combination of BOL and EOL performance is realized. A major influence on radiation resistance is the cell thickness, and dramatic increases in radiation resistance have resulted from use of silicon slices thinner than 4 mils.

Thin Cell Development

The cell processes which give high output have been successfully applied to thin slices. Mechanical yields have improved significantly, and the electrical output has increased to within 95% of that of similarly processed thicker cells, with considerable increase (16-23%) in radiation reistance; in fact the highest power output after fluences $\sim 10^{15}$ 1 Mev electrons/cm^2 is obtained for 2 mil-thick cells. Also the power-to-weight ratios have increased from 0.35 W/g to 1.7 W/g (for cells with contacts).

PRESENT DEVELOPMENT TRENDS

The thin cell advances have led to several associated trends, including the development of suitable array-formation methods, and increased study of reverse-illuminated structures (interdigitated contacts, tandem junction cells).

Efficient cells for use with concentrators (up to 16% at 40 AMO suns) have been made, and are ready for space-use if required. These cells combine much of current space cell technology with modifications (such as computer aided grid design) required for operation at higher insolation levels. Cells with enhanced IR output are also available for combination in high performance tandem cell concentrator systems.

Several contact variations are available, including some with improved high temperature performance (for use in laser-hardening, ES bonding or possible annealing of radiation damage), or with both contacts on the back surface (wraparound or reverse illuminated). Also present cell technology can be adjusted to allow good bonding by soldering or by several different welding techniques.

The increased voltage available from highly doped silicon is being evaluated to check the overall effect on output, and the extent of the increased sensitivity to radiation damage. Technology is also available to compare VMJ cells directly with 50 μm cells.

INCREASED CAPACITY, LOWER COST ARRAYS

Although much of the present low cost terrestrial cell technology is not yet ready for space-use, the present production capacity using the methods listed above can accommodate cell production schedules for multi-100 KW missions. There is associated promise of space cell costs below $30/watt (for slight relaxation in non-technical specifications but no reduction in performance) even before additional automation is introduced.

Thus, in summary, silicon solar cell technology has continued to develop, and provides a sound base for present and projected future space missions.

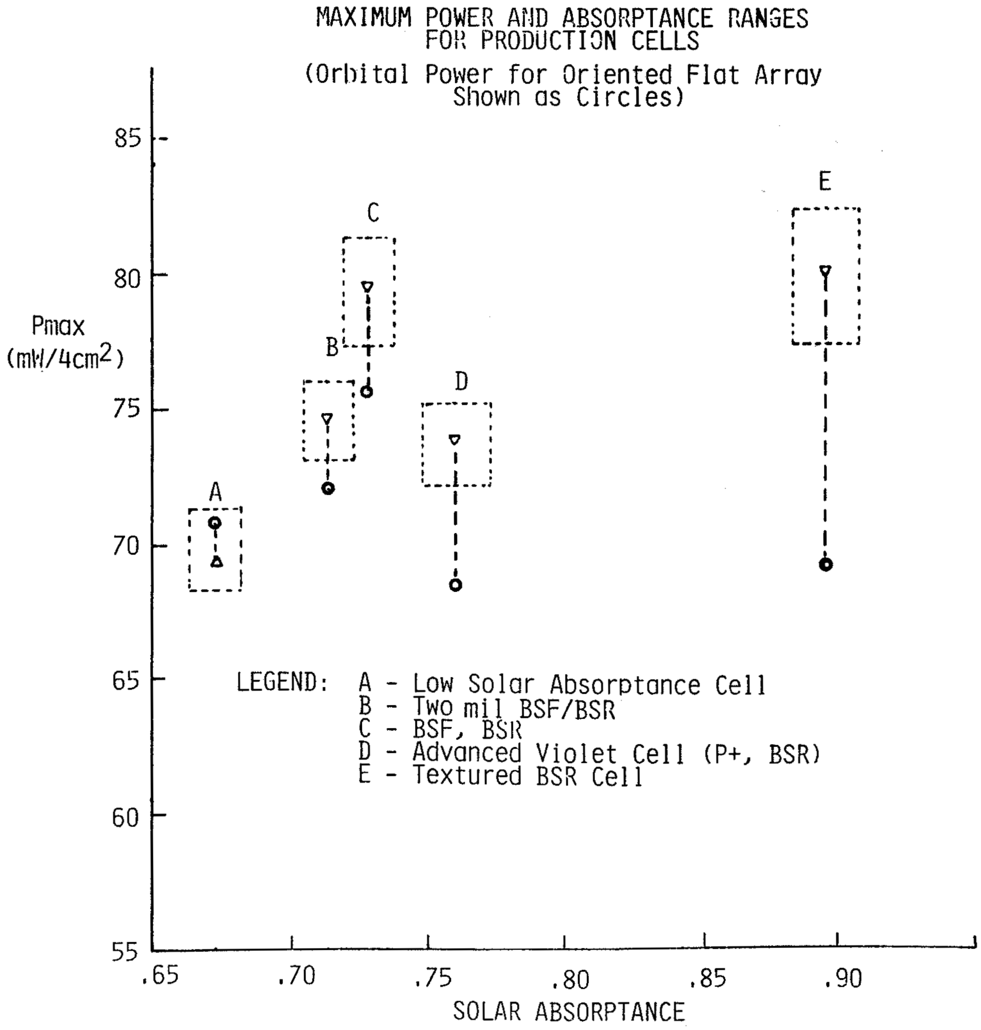
MAXIMUM POWER AND ABSORPTANCE RANGES FOR PRODUCTION CELLS
(Orbital Power for Oriented Flat Array Shown as Circles)
Pmax (mW/4cm^2)
85
80
75
70
65
60
55
.65
.70
.75
.80
.85
.90
SOLAR ABSORPTANCE
A
B
C
D
E
LEGEND: A - Low Solar Absorptance Cell
B - Two mil BSF/BSR
C - BSF, BSR
D - Advanced Violet Cell (P+, BSR)
E - Textured BSR Cell

Figure 1