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Optimization and Performance of Space Station Freedom Solar Cells

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High efficiency, large area and low cost solar cells are the drivers for Space Station solar array designs. The manufacturing throughput, process complexity, yield of the cells and array manufacturing technique determine the economics of the solar array design. This paper describes the cell efficiency optimization of large area (8cm by 8cm), dielectric wrapthrough contact solar cells. The results of the optimization are reported and the solar cell performance of limited production runs is reported.

Introduction

The Space Station solar cell is a shallow diffused N on P silicon solar cell with back surface field manufactured from P-type, boron doped, single crystal silicon with a base resistivity of 7 to 14 Ohm-cm. The cell size is 8cm × 8cm and the nominal thickness is 8 mils.

Both N and P contacts are located on the back side of the solar cell. The N contacts are wrapped through four interior holes, isolated from the P contacts by SiO_2 dielectric layer. The cell is equipped with a gridded back and a back side optical coating, designed to optimize transmission of solar energy in the range of 1.1 to 2.5 micrometer. This IR transmission allows the solar cell to operate at low temperature and improve on-orbit electrical performance. The coverglass is a 5 mils thick ceria-doped borosilicate glass. The top surface of the coverglass is optically coated with UV reflecting coating designed to reject UV radiation and reduce solar absorptance. The solar cell and coverglass are bonded together with an optically clear DC93-500 adhesive.

The original cell efficiency requirement was approximately 12.8 percent. Since then, the requirement was raised to as high as 14.4 percent and the final efficiency was negotiated to 14.1% (2420mA at 495mV). In early 1988, ASEC developed the required solar cells. Since the standard cell for simulator calibration for this newly developed cell was not available, ASEC chose one of the in-house standard cells to calibrate the solar simulator to evaluate these new cells. In summer of 1988 a balloon flight standard cell for this newly developed cell was flown by JPL. The cells were then retested electrically using the new balloon flight standard cell and found that the solar cells were 3.4 percent below the requirement of the specifications.

Cell Efficiency Optimization

It was obvious that cell efficiency optimization was required to achieve the requirement of the specifications. ASEC worked to optimize the cell efficiency. The cell efficiency goal of 14.5% under production conditions was set. Table 1 shows the performance status prior to optimization and the goal for optimization.

The approach for optimization was to fine-tune the existing process using production equipment and personnel under close supervision by engineers and production management. This process reduced production transfer time. The production personnel were part of the optimization team from the start and many of the potential start-up problems were reduced.

V_{oc} Optimization

The achieved V_{oc} of 615.5 mV was considered good. It was felt that some marginal improvement can be achieved by optimizing the back surface field process. Boron nitride diffusion process is used to form the back surface field for this program. The V_{oc} optimization process was to vary the boron diffusion temperature while keeping all other processes unchanged. Three (3) boron diffusion temperatures were chosen, baseline temperature, 25°C above baseline temperature and 50°C above baseline temperature. For simplicity, 2x4cm top-bottom contact cells were made for these experiments. Two sets of experiments were carried out to assure repeatability. The AMO electrical output for all three type of cells were evaluated to determine V_{oc} improvement.

I_{sc} Optimization

It was determined that I_{sc} improvement of 3 to 4% could be achieved. I_{sc} optimization included designing a new front grid mask to reduce gridline shadowing and series resistance. This new front mask design included:

- Reduction of metalization dot size around the wrapthrough holes.
- Reduction of gridline width, and
- Increase gridline density to handle solar cell with shallow junction.

An improved photoresist process was proposed to be used in manufacturing of Space Station cell. This improved photoresist process allows narrow and tall gridlines to be formed on solar cells with clean and sharp edges, and reduced shadowing. With new mask design and implementation of improved photoresist process, it was estimated that cell efficiency improvement approximately 3% would be achieved.

The next area of I_{sc} optimization was to reduce the solar cell junction depth further and to fine-tune the AR coating to match the junction depth. The junction depth experiment was performed by diffusing the N + junction at 25° and 50° below the baseline diffusion temperature. 2x4cm solar cells with baseline BSF were made and evaluated electrically. Particular attention was paid to the improvement of short circuit current without sacrificing the loss in curve filled factor.

CFF Optimization

The CFF Optimization included:

- Improved CVD dielectric
- Improved wrap-through hole geometry

The dielectric layer in and around the wrapthrough holes must fulfill several functions. It must be impermeable to reduce any possible shunting paths caused when the wrapthrough metal layers are deposited. In addition, the dielectric layer which is present under the N welding pads must not degrade during the welding pulse, or impair the adhesion of the welded contact. Three CVD dielectric systems, APCVD, LPCVD and PECVD were considered. It was determined that an APCVD system would be a suitable system for ASEC due to the nature of the CVD dielectric process, and this system is now used.

It was also determined that the wrapthrough hole geometry needed improvement. After laser drilling of the holes, the silicon damage silicon surfaces were removed by chemical etching. This chemical etching also smoothed the surface and rounded the wrapthrough holes allowing good coverage of dielectric material in and around the wrapthrough hole, thus reduce shunting paths caused when wrapthrough metal layers are deposited. Figure 1 shows a typical wrapthrough hole geometry after optimization.

Production of Optimized Cell

Upon completion of the optimization process, limited prototype solar cells were made to verify the optimization results. The verification process was successful and documentations were established.

The first production quantity required for delivery was 970 assemblies. This production run was carried out with full documentation. The production line was closely monitored by engineers and supervision to assure smooth production flow.

Solar Cell Performance

Figure 2 shows the open circuit voltage distribution of 558 solar cell assemblies tested under AMO condition and 28°C. The solar simulator was calibrated using a Space Station balloon flight standard cell flown late this summer. The open circuit voltage ranges from 590mV to 630mV with an average of 618.9mV. The average V_{oc} met the established goal of 618 mV. Figure 3 shows the I_{sc} distribution for the same 558 cell assemblies. The I_{sc} distribution is tightly controlled with an average of 2733mA (43.6mA/cm2). The average I_{sc} is 5% above the established goal. Figure 4 shows the efficiency distribution of the same 558 cell assemblies. The efficiency ranges from 13.1% to 15.4% with an average of 14.6% (2495mA at 495 mV). The efficiency of the cell is well above the requirement of the specification of 14.1%. Figure 5 shows the typical spectral response of a typical Space Station solar cell showing good response in both the blue and red regions. The Space Station solar cell has currently undergone qualification tests. Electron radiation test and high temperature soak test are completed and passed the qualification test. The remainder of the qualification will be completed by the end of November. Figure 6 shows the results of 1MeV electron radiation.

Table 1: Solar Cell Performance Status Prior to Optimization and Optimization Goal

Electrical Parameters	Status Prior to Optimization	Optimization Goal
Voc (mV)	615.5	618
Isc (mA)	2516	2600
CFF (%)	74.7	76.5
EFF (%)	13.7	14.5

FIGURE 1

Typical Wrapthrough Hole Profile of Space Station Cell

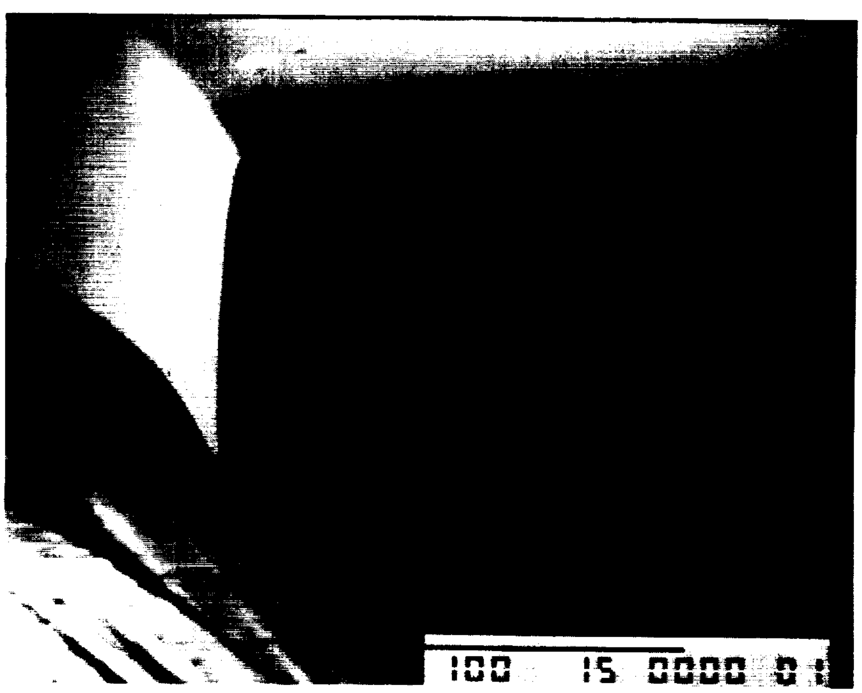
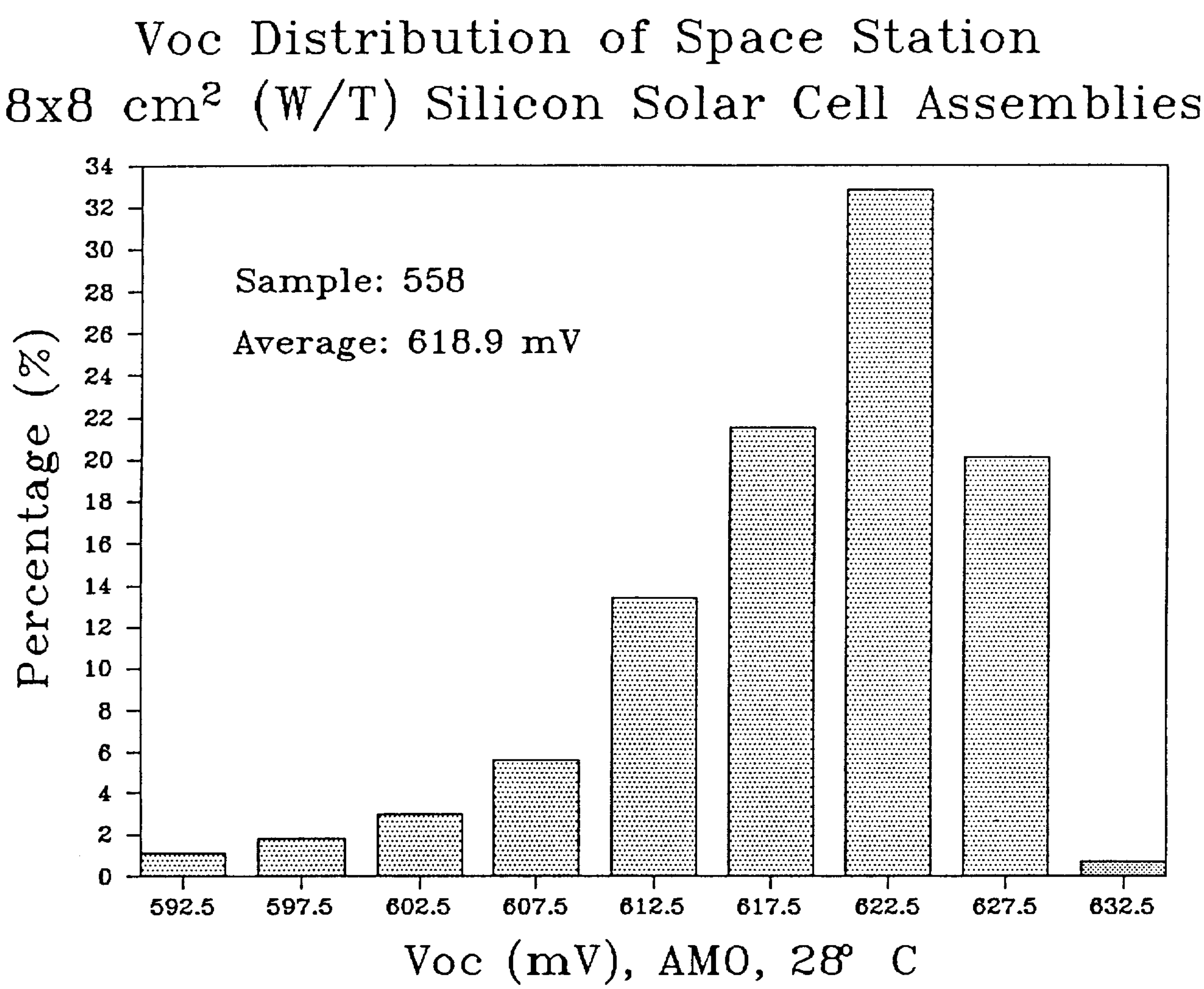


Figure 2



Voc Distribution of Space Station
8x8 cm2 (W/T) Silicon Solar Cell Assemblies
Sample: 558
Average: 618.9 mV
Percentage (%)
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
592.5
597.5
602.5
607.5
612.5
617.5
622.5
627.5
632.5
Voc (mV), AM0, 28° C

Figure 3

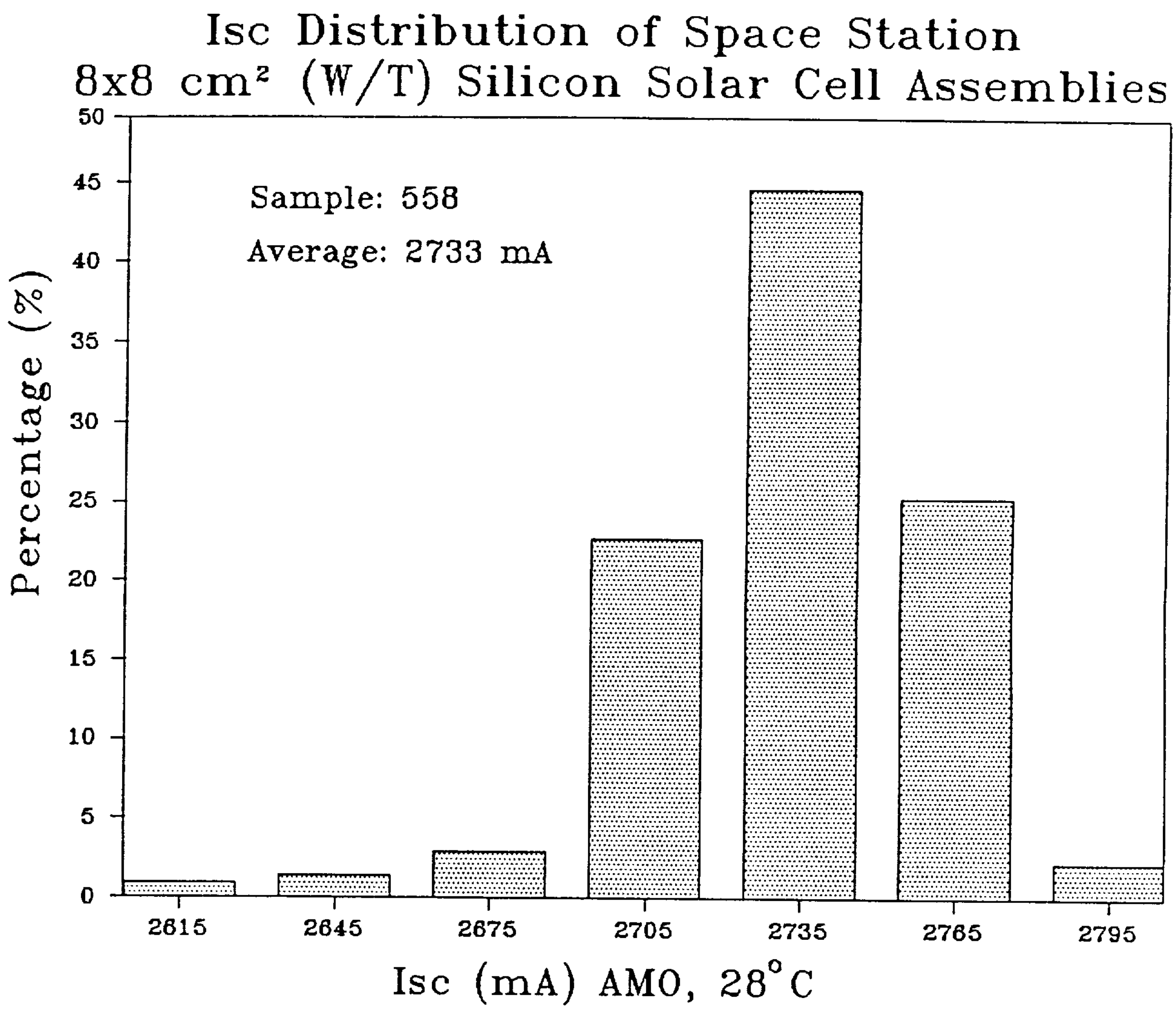

Isc Distribution of Space Station
8x8 cm² (W/T) Silicon Solar Cell Assemblies
Sample: 558
Average: 2733 mA
Percentage (%)
0
5
10
15
20
25
30
35
40
45
50
2615
2645
2675
2705
2735
2765
2795
Isc (mA) AMO, 28°C

Figure 4

Efficiency Distribution of Space Station 8x8 cm^2 (W/T) Silicon Solar Cell Assemblies

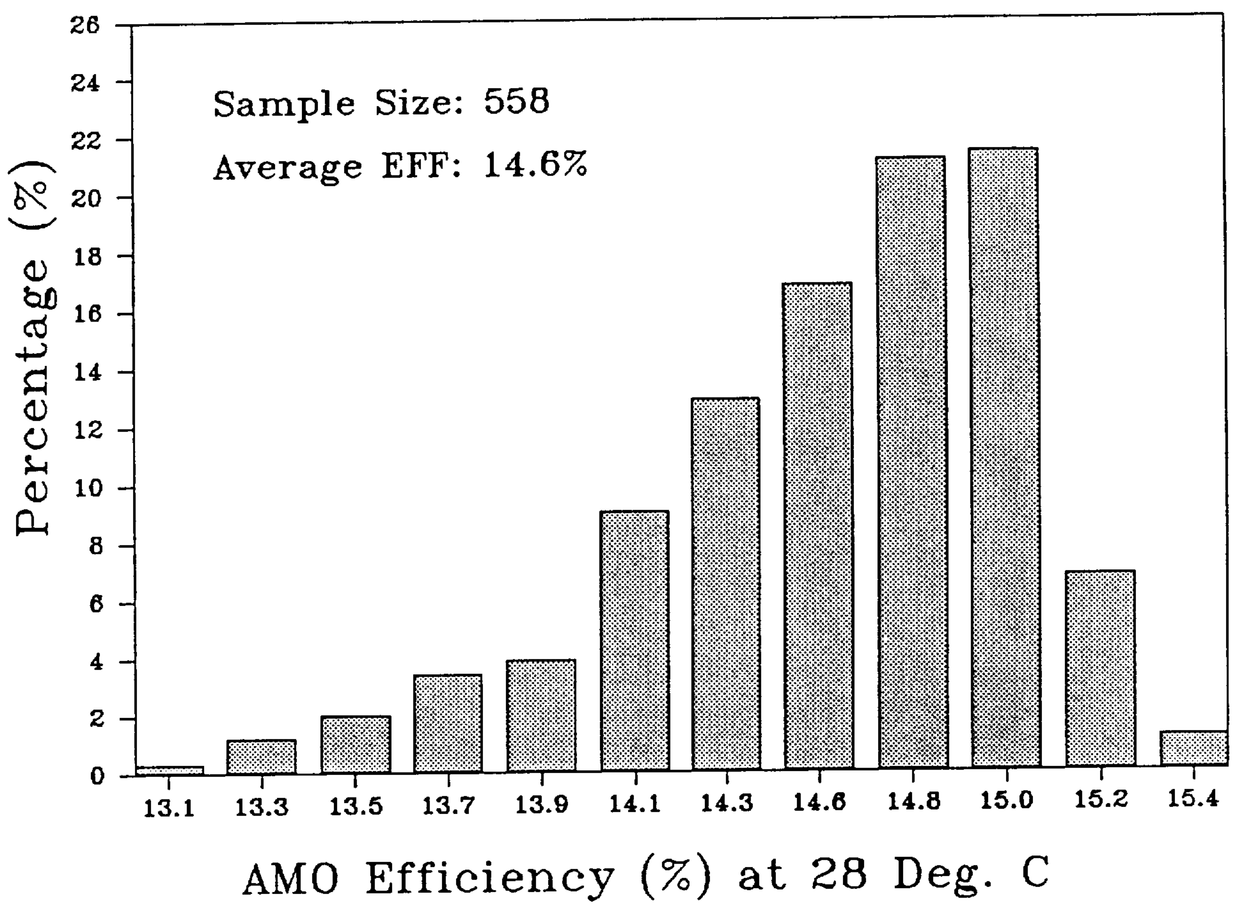


FIGURE 5

Typical Spectral Response for Space Station Solar Cell

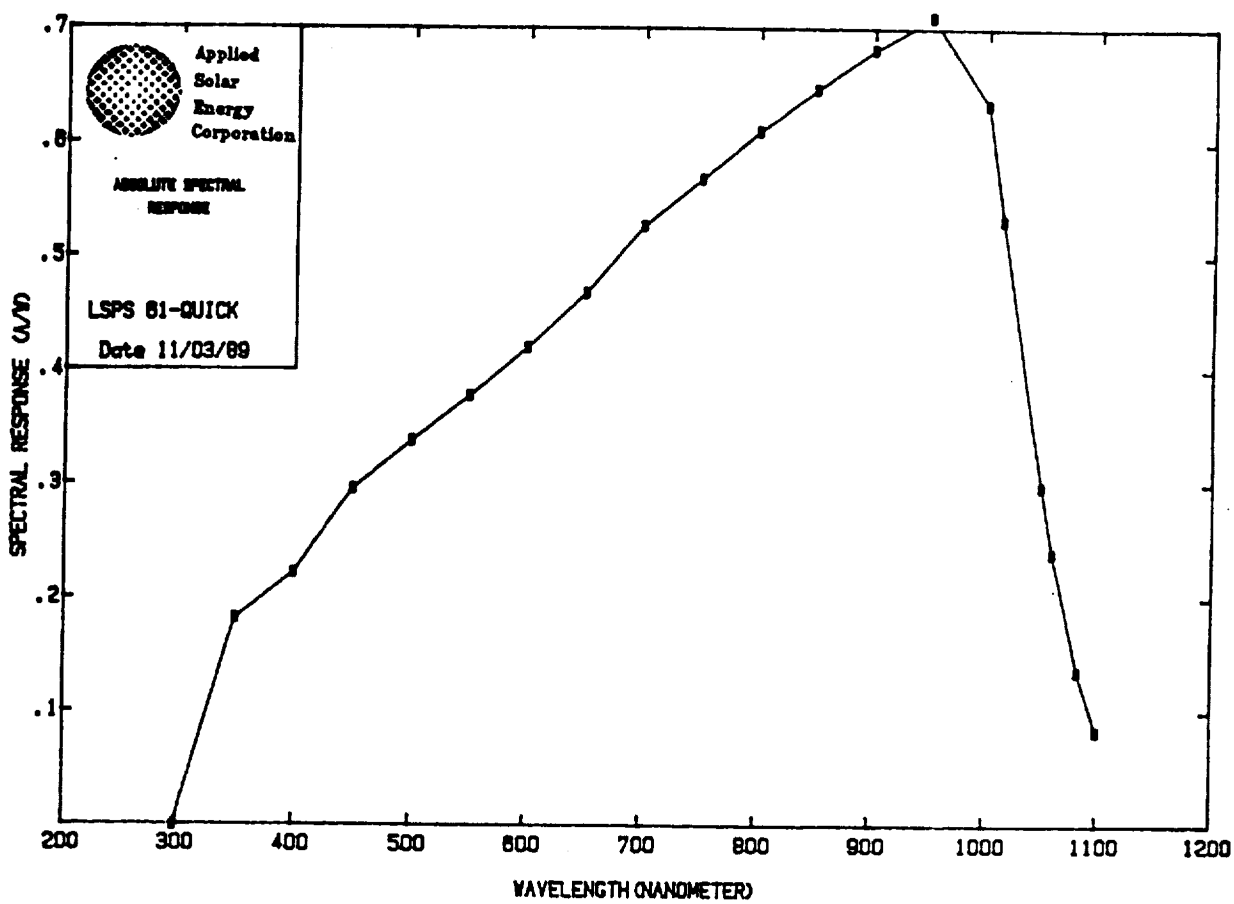


FIGURE 6

1 MeV Electron Radiation Results for Space Station Solar Cell