SPACE QUALIFICATION TEST OF a-SILICON SOLAR CELL MODULES

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Abstract

The basic requirements of solar cell modules for space applications are generally described in MIL-S-83576 for the specific needs of the USAF. However, the specifications of solar cells intended for use on space terrestrial applications are not well defined[1,4,5]. Therefore, this qualification test effort was concentrated on critical areas specific to the microseismometer probe which is intended to be included in the Mars microprobe programs. Parameters that were evaluated included performance dependence on: illuminating angles, terrestrial temperatures, lifetime, as well as impact landing conditions. Our qualification efforts were limited to these most critical areas of concern. Most of the tested solar cell modules have met the requirements of the program except the impact tests. Surprisingly, one of the two single PIN 2x1 amorphous solar cell modules continued to function even after the 80,000G impact tests. The output power parameters, Pout, FF, Isc and Voc, of the single PIN amorphous solar cell module were found to be, 3.14mW, 0.40, 9.98mA and 0.78V, respectively. These parameters are good enough to consider the solar module as a possible power source for the microprobe seismometer. Some recommendations were made to improve the usefulness of the amorphous silicon solar cell modules in space terrestrial applications, based on the results obtained from the intensive short term lab test effort.

Introduction

Various amorphous solar cell modules were obtained from Iowa Thin Film Technologies on July 8, 1996. These modules[2] were to be tested as part of a program to identify the qualification requirements dictated by the environmental specification[3] for solar cells in order to utilize them as a potential power source for a microseismometer, which is one of the many Mars Microprobe programs of the New Millennium project. Much of the electronics will actually be shield by some 3mm-thickness of steel, but the solar cell modules will have only minimal shielding. The purpose of this study was to develop the needed space terrestrial qualification guidelines on different types of state-of-the-art solar modules that may be applicable for use as the power source of the Mars microseismometer.

Test Results and Discussions

1 External Visual Inspection

Three major different groups of twelve (12) different kinds of samples as listed in Table I were examined and documented. No major visual defects were seen. A typical 5x1 single PIN module is shown in Figure 1.

Table I. Parts List.

Parts	Encapsulation	Serial No.	Adhesive	Operation/Comment	No. of Parts
1	Polyester		EVA thin/0.1 mil	3V,45mA	8
2.	Polyester 1.5 mil		EVA 0.2mil		45
3.	Tefzel		EVA 18 mil	3V,90 mA	3
4.	Tefzel		EVA		4
5.	None		None	R379(4),F83-86(4)	
6.	Tefzel		EVA	3M Adhesive Foil 6x2 cells	3
7.	Tefzel		EVA	F-8257 Adhesive Foil 6x2 cells	3
8.	Tefzel		EVA	Indium/Tin Solder Paste	3
9.	Tefzel		EVA	Bismuth/Tin Solder Paste	3
10.	Tefzel		EVA	3M Adhesive Foil 12x2 Cells	5
11	Tandem	357			5
12.	Tandem	395			5

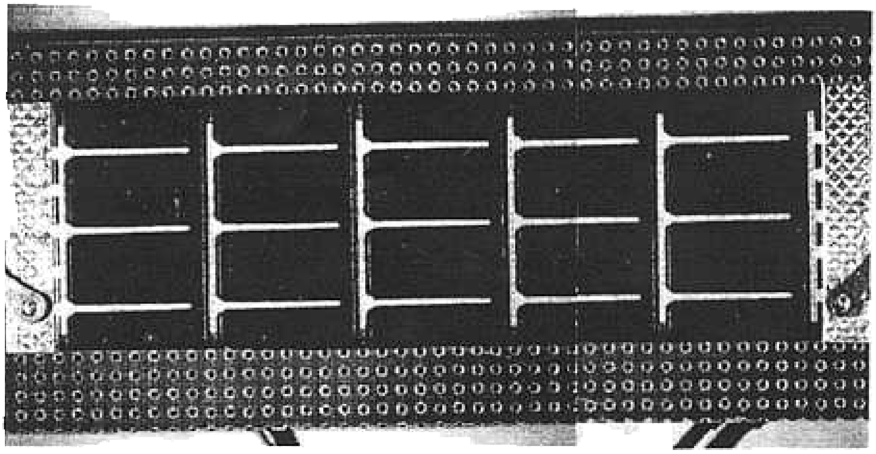

Figure 1. External Visual Inspection of a Typical 5 x 1 Single PIN Amorphous Solar Module.

2. I-V Characterization

I-V characteristic measurements of the modules in dark and light at 1/2 Martian sun (28.5 mW/cm^2) were performed as a required specification of the Mar's probe. The characteristics (Isc. Voc, Fill Factor, Output Power) of the modules agrees well with the nominal values given by the manufacturer within 5%. A typical I-V characteristics of the polyester encapsulated amorphous silicon solar cell module (MPV-P) is shown in Figure 2.

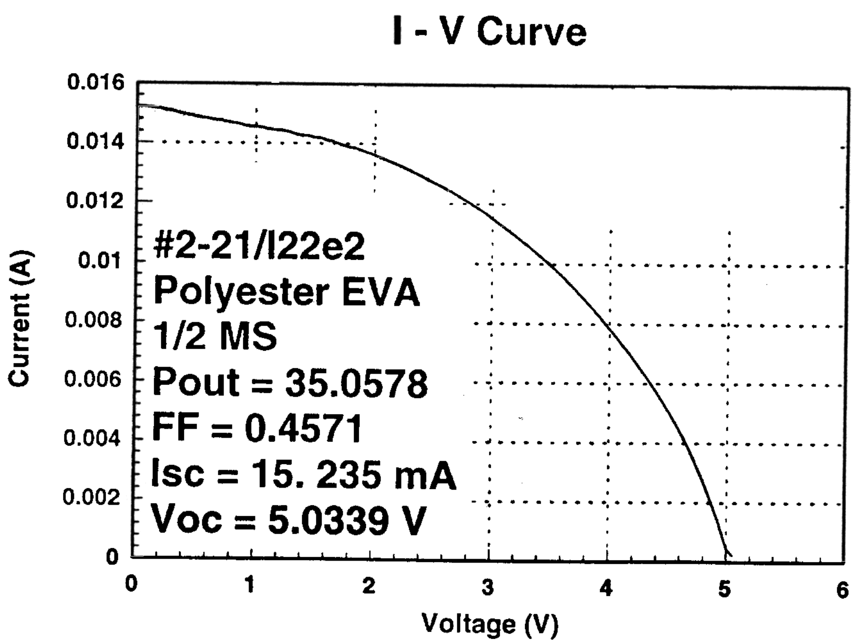

Figure 2. I-V Characteristic of a Polyester Encapsulated Amorphous Silicon Solar Cell Module.

3. Illuminating Angle Dependence

The power generation of the solar cell module depends upon the angle of the solar illumination at the microprobe landing site[3]. The maximum power output of the module was compared with the cosine of the sun's illumination angle. At 40 degrees of tilt for example, the power output was reduced to 60% (Figure 3). The output power is still high enough to supply the needed power for the seismometer.

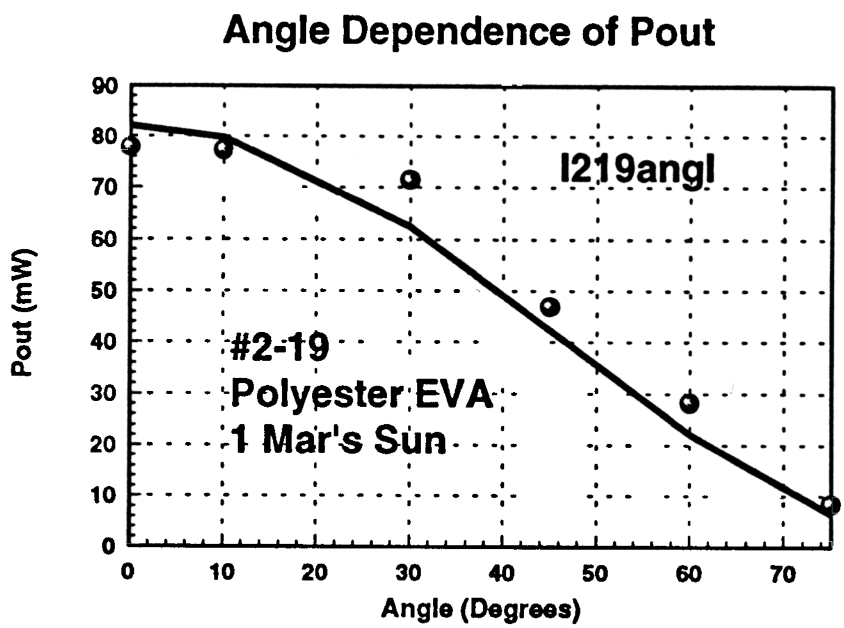

Figure 3. Angle Dependence of the Amorphous-Si Solar Module Power Output.

4. Temperature Dependence

The optimum performance of the solar module depends upon the module operating temperature. The projected range of operating temperatures for the microprobe is from -70 to +25° C. The maximum output power of a polyester encapsulated module (#2-20) was measured. The power output was reduced in a linear fashion at the lower temperature range. At -60°C, for example, the maximum output power was reduced to 58% of the output power at +25°C (Figure 4). High Temperature tests (room temperature - +150°C) were also performed. The maximum output at +150°C was reduced to 35% of the output power at +25°C (Figure 5). Note that the maximum power output decreases when the operating temperature of the solar cell module is either cooled or heated from room temperature, probably due to the amorphous nature of the silicon material.

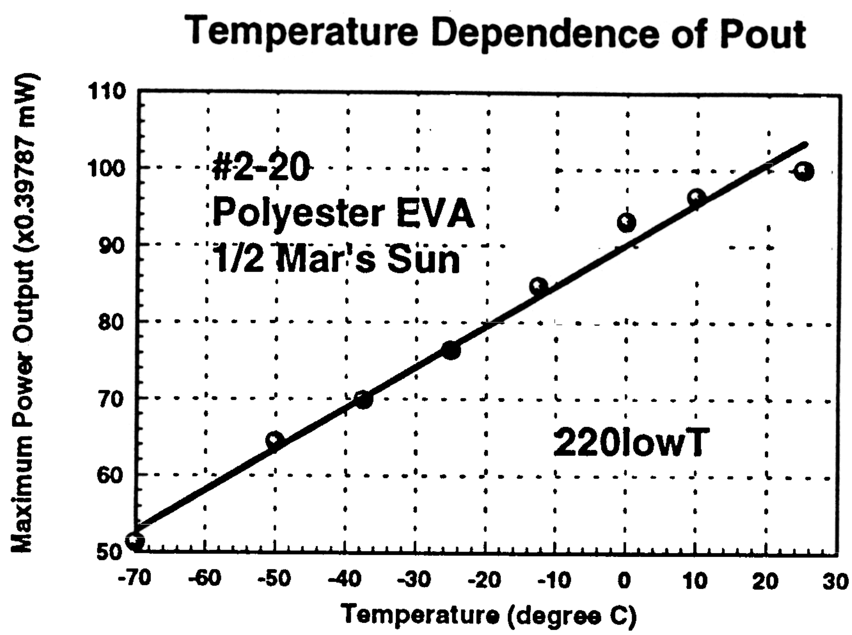

Figure 4. Temperature Dependence of the Amorphous-Si Solar Module Power Output.

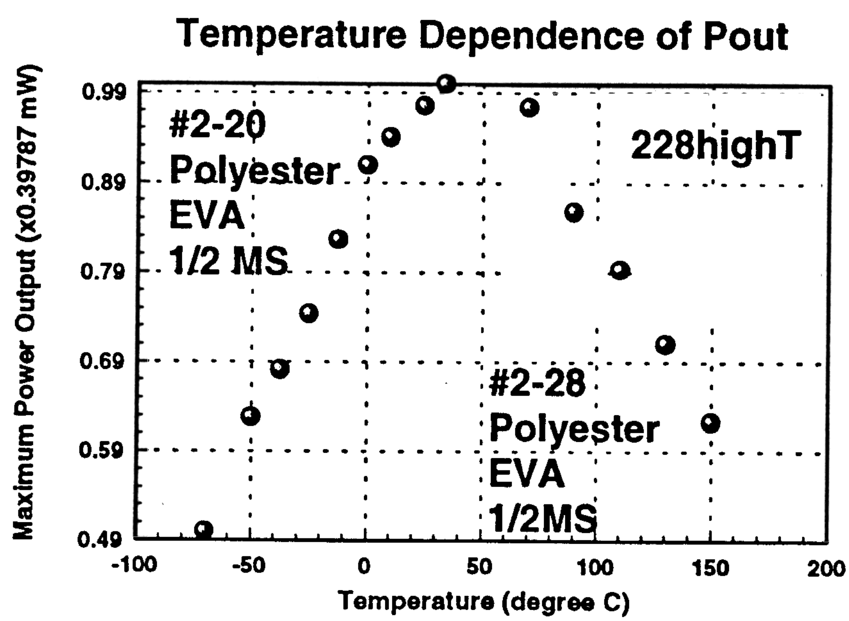

Figure 5. High Temperature Dependence of the Amorphous-Si Solar Module Power Output.

Aging of the Out Power

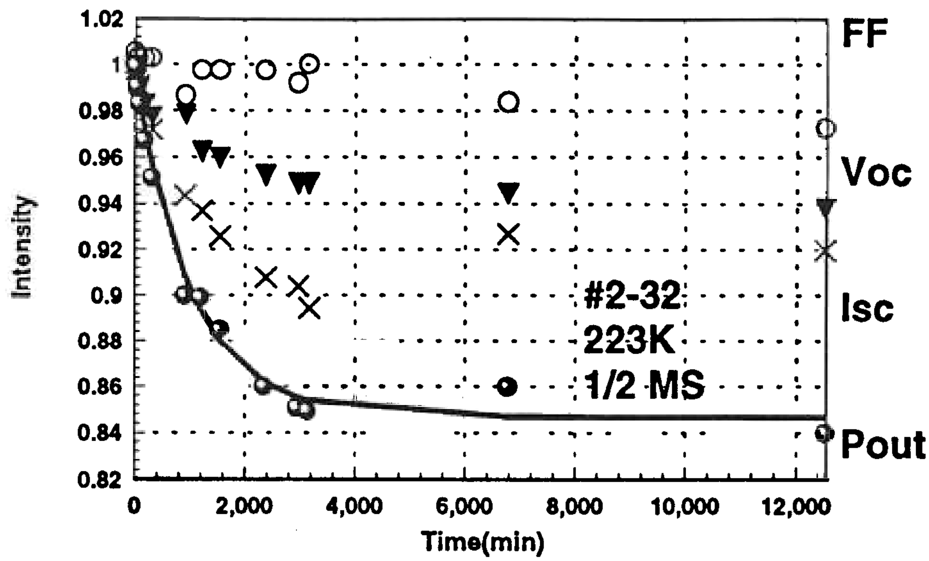

Figure 6. Illumination Time Dependence of the Amorphous-Si Solar Module Power Output at 223K.

5. Time Dependence

The demonstrated reliable lifetime of the module should exceed the required life expectancy for a ten day mission. One of the polyester encapsulated EVA modules was kept at 223K for 12,531 minutes (~9 days) under the ½ Martian sun. The maximum power output was down by 15% within two days in an exponential fashion and stayed at that level as shown in Figure 6. The maximum power output characteristics are similar even at 248K as shown in Figure 7. However, the power output was degraded by 12 percent.

Performance Degradation at 248K

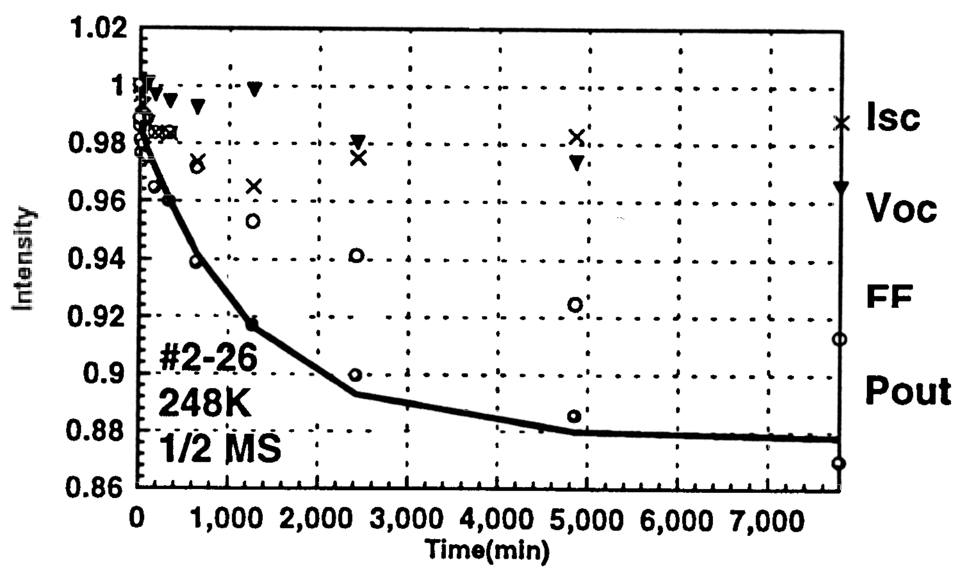

Figure 7. Illumination Time Dependence of the Amorphous-Si Solar Module Power Output at 248K.

6. Absorption of the Encapsulation EVA

One of the solar module encapsulants, Tefzel, was tested for absorption spectrum by using Fourier Transformation Spectroscopy for a baseline reference of the degradation caused by solar illumination. Reflection from the stainless steel substrate, polyester encapsulated solar cell module can be tested later as needed in order to measure the degree of degradation of the encapsulant using a reflection sample holder.

7. Impact tests

One of the most critical parameters of a solar cell as a power generating source for the microprobes is the survivability of the module after an impact landing at 80,000 Gs[3]. A series of single PIN solar cells and tandem PIN solar cells were characterized before and after application of the simulated impacts. In these tests all the samples were modified to fit into the impact test chamber. All four different tandem PIN samples were found to be electrically shorted after the applied impact, reducing the output power of those modules down to 1.7 microwatts from 35 milliwatts. Two of the single PIN cells encapsulated with polyester using EVA adhesive were also modified to 2x1 from a 5x1 matrix to fit the impact test chamber, and covered with a plastic film before the impact test. Surprisingly, one of the two tested amorphous solar cell modules survived the 80,000G impact. The maximum power output of the module at ½ Martian sun was reduced by 65%. This reduced power output is still sufficient to supply the needed power for the microelectronic seismometer task.

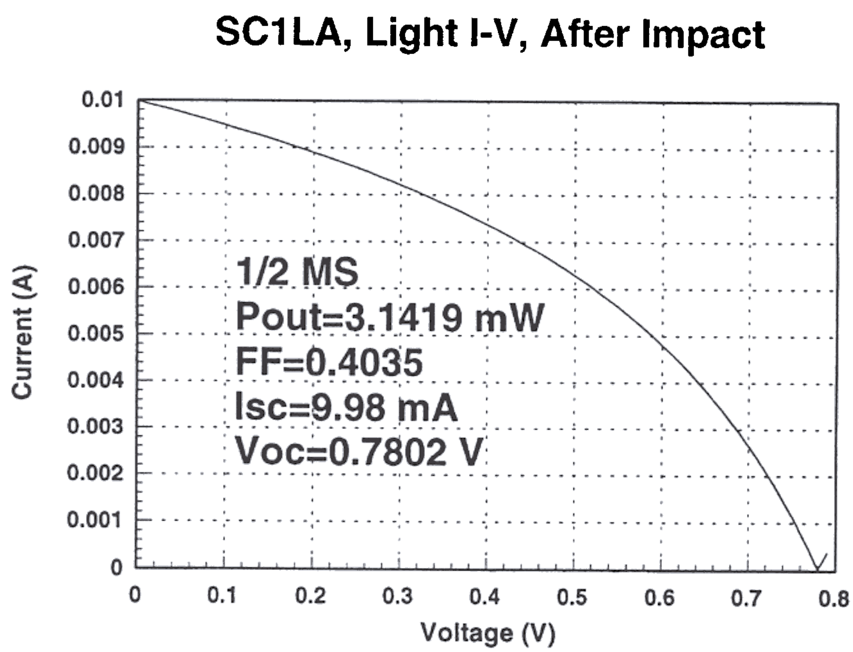

Figure 8. I-V Characteristic of the Amorphous Solar Module after the 80,000G Impact Test.

The PIN diode characteristics of the module still exhibited the needed fill factor (40%) (Figure 8) despite the fact that physical defects were visible (Figure 9) including a stain and scuffing on the front surface and some damaged silver electrodes. The device characteristics of the module before and after the impact test are listed in Table II.

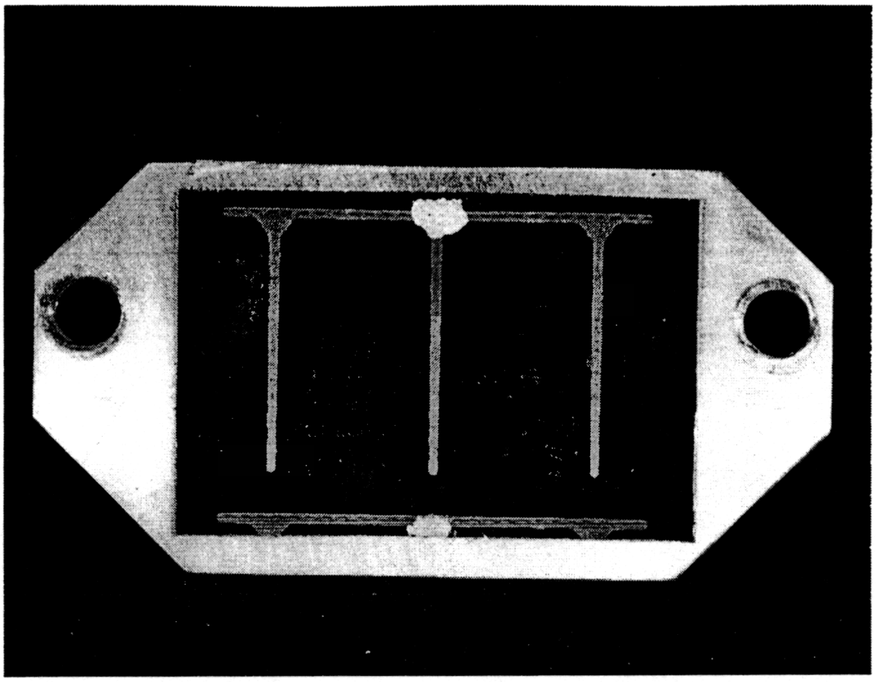

Figure 9. Visual Damage Inspection of the Impact Tested Amorphous Solar Cell.

Further impact tests of single PIN solar cell modules are in progress to improve the reliability of the module, especially in the electrical contacts.

Table II. Single Cell Impact Test Results

		R_{sheet} (Ω) At Dark	R_{series} (Ω) At 1/2 Mars Sun	R_{shunt} (Ω)
Cell #1	**Before**	618.6	17.01	500.00
	After	25.00	24.55	220.75
Cell #2	**Before**	252.2	19.47	666.67
	After	26.18	26.18	11.06

8. Leakage Test

Some of the failed samples after the impact tests were photographed to find the leakage spots by using an Infrared Camera. Leakage spots were found in areas within the active cell as well as near the silver electrode grid of the failed tandem PIN solar modules as shown in Figure 10. However, no hot spots or breakdown spots were observed on single PIN solar cell modules. This may indicate that the leakage path of the failed modules may be a short within the conductive series contact layers rather than a breakdown of the PIN cell structure. Further tests are scheduled in order to improve the electrical contacts.

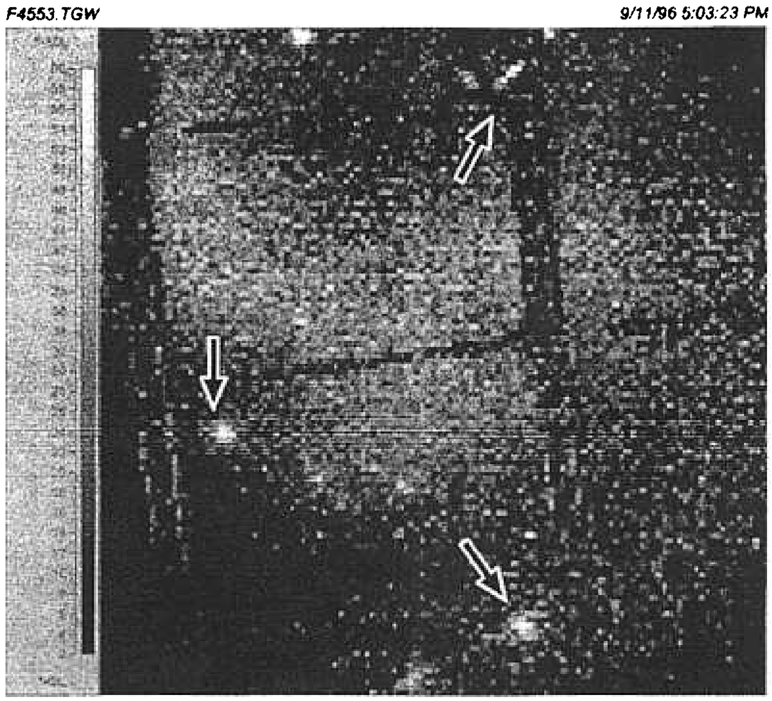

Figure 10. Possible leakage spots of a good solar module as observed by the Infrared Camera.

9. Cross Section Analysis

As a part of the effort to ascertain the manufacturer's workmanship integrity, a cross section of a single PIN structure was performed by fracturing a cell that was made brittle by immersion in liquid nitrogen. During SEM examination of cross sectioned samples, damage to the underlying dielectric isolation caused by the laser scribed grooves within the electrical contacts was revealed as a potential leakage path.

Conclusions

Most of the test qualification results obtained for the single PIN amorphous solar cell modules were satisfactory. These modules are suitable for consideration as the power source for the seismometer of the Mars microprobe. However, the electrical contacts of the module should be improved before final selection of qualified modules. Of special importance is the need to identify and test improved encapsulation materials and techniques to increase the survivability of the module against impact damage.

Additional testing is in progress to improve the conductive contacts and the protective encapsulant of the single PIN module against damage induced by the stress of high velocity impact anticipated for the Mars microprobe application.

Acknowledgments

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