DEMONSTRATED RESULTS OF WELDED AND SOLDERED INTERCONNECTIONS

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Solar cell modules with welded and soldered interconnections were constructed using a flexible substrate material. These modules were thermally cycled between ±80 °C at rates >100 cycles/day to demonstrate survivability under simulated low Earth orbit (LEO) temperature conditions. The modules, cycled in an inert atmosphere, showed durability for >36 000 cycles (6 yr LEO).

INTRODUCTION

In April 1982, NASA embarked on a demonstration to compare the ability of state-of-the-art interconnections on welded and soldered silicon solar cells to withstand simulated low Earth orbit (LEO) thermal-cycle conditions. It was believed that soldered contacts would last little more than 5 years in a space station LEO. If welded contacts could be made reliably, the problems associated with soldered contacts would be eliminated and longer lifetimes in orbit could be achieved. Lewis Research Center began a joint effort with the Jet Propulsion Laboratory (JPL), as the prime contractor, and four subcontractors - Lockheed Missiles & Space Corporation (LMSC), TRW, Hughes Aircraft Company, and Hughes/Spectrolab. These groups were joined together in a common interest to demonstrate the durability of soldered and welded interconnections on silicon solar cells mounted on flexible substrates.

SOLAR CELL MODULE CONSTRUCTION

Five welded and three soldered modules were fabricated by each subcontractor. Each module consisted of 0.02 cm thick, silicon solar cells. Of these modules, one soldered and three welded were selected for cycling. All module materials were to be capable of withstanding the space environment and were to be readily available in production, in pilot production, or in advanced development. The module substrate materials were to be flexible materials such as Kapton, fiberglass, cloth, etc. All modules were to provide at least 140 W/m^2 when measured at 28 °C under AMO illumination. Welded modules were to be capable of at least 90 W/kg. State-of-the-art fabrication processes including welding and soldering were to be used to produce the modules.

Because of facility limitations associated with the 5.9 cm by 5.9 cm wraparound (W/A) solar cell, LMSC constructed their nine cell modules into three series strings using both soldering and parallel-gap welding to interconnect the 0.0036 cm thick, rolled copper, integrated circuit to the cells (table I). TRW used 2 cm by 4 cm conventional cells with front and rear contacts, but they elected to build a module of 3 by 6 series-parallel configuration. TRW's solar cell interconnects were 0.0049 cm, silver clad Invar which were soldered and parallel-gap welded. Both LMSC and TRW used Kapton for the substrate material. Hughes and Hughes/Spectrolab constructed their modules with conventional 2 cm by 4 cm solar cells in a series-parallel configuration. The substrate material was a Kevlar fabric rigidized with epoxy. The Hughes/Spectrolab solar cell interconnects were 0.0049 cm thick, silver plated Invar which were soldered or parallel-gap welded. Hughes solar cells were soldered or ultrasonic welded with a silver, 0.0127 cm thick mesh, interconnection.

TEST ENVIRONMENTS

Because there were no standards for thermal-cycling modules for a LEO orbit condition, the following conditions were used for this test. The temperature cycle was to be $\pm$80 °C, with a variance of <5 °C, and cycling was to be in an inert atmosphere. TRW elected to cycle in a vacuum, while the other contractors elected to cycle in dry nitrogen. Cycling times were to be accelerated to about 15 min/cycle. The goal of 5 years in LEO or 30 000 cycles was set as a minimum test. Nondestructive inspections consisted of visual inspections (10x magnification) as well as electrical measurements (current/voltage (I-V) at 28 °C in an AMO solar simulator). These tests were to be performed at 0, 500, 1000, 2000, 4000, 8000, 12 000, 18 000, 24 000, and 30 000 thermal cycles.

TEST RESULTS

Figure 1 shows plots of P/PO and FF/FFO versus thermal cycles. Since the Hughes and Hughes/Spectrolab test results were exactly the same, just one plot is necessary. In this case, where one plots only the fill factors, the problems in solar simulation tend to fall out leaving a more ideal plot. Although the data for the four Hughes and four Hughes/Spectrolab were averaged together for the plot, the range of differences was little more than 1 percent. They also cycled their cells an additional 6000 cycles to a 6 year LEO (36 000) with no apparent degrading based on fill factor. The three welded TRW modules (whose cells were cycled in a vacuum) showed little power degradation. Any differences could have resulted from testing inaccuracy. LMSC had two starts in their test. The first cells failed rapidly because of poor adhesion of the silver coating. This fault was verified by pull tests. New cells were made using silver which was specially prepared to have less oxygen. Pull tests showed them to be much stronger, so they proceeded with another test, which is also plotted. The plot is an average of nine, three cell series strings mounted in three modules. The average power for these strings degraded 4 percent, with a variation from the average of 4 percent. This test was concluded early (12 000 thermal cycles) because of a previous commitment for the cycling facility. LMSC believes that the loss in power was caused by oxygen in the system. This oxygen caused microcrack creep at the welds. Solar cells (2 cm by 4 cm) being cycled in vacuum in another facility are showing little or no failure.

CONCLUSIONS

Soldered or welded interconnects have survived equally well for a simulated 6 years in LEO. Survivability of welded contacts, both parallel-gap welded and ultrasonic welded, were demonstrated during this test. Further cycling of these modules should be conducted to the expected requirements of the space station (now believed to be 10 yr in LEO). Further development of the 5.9 cm by 5.9 cm solar cells with wraparound contacts and integrated printed circuit contacts should be conducted to advance them to the level demonstrated by the conventional (2 cm by 4 cm) solar cells.

TABLE I. - FINAL MODULE DESIGN

Experimenter	Cell size, cm	Inter-connections	Module matrix	Number of modules	Atmosphere
LMSC	5.9 x 5.9 silver (W/A) contacts	0.0036 cm rolled copper	9 Cell module 3 Cell series 3 Cell strings	3 Welded 1 Soldered	Nitrogen
Hughes	2.11 x 4.03 conventional silver contacts	0.0011 cm silver foil mesh	9 Cell module 3 by 3 Series-parallel	4 Ultra-sonic welded 2 Soldered	Nitrogen
Hughes/ Spectrolab	2.11 x 4.03 conventional silver contacts	0.0049 cm silver plated Invar	9 Cell module 3 by 3 Series-parallel	4 Parallel-gap welded 2 Soldered	Nitrogen
TRW	0.11 x 4.03 conventional silver contacts	0.0049 cm silver clad Invar	18 Cell module 3 by 6 Series-parallel	3 Parallel-gap welded 2 Soldered	Vacuum

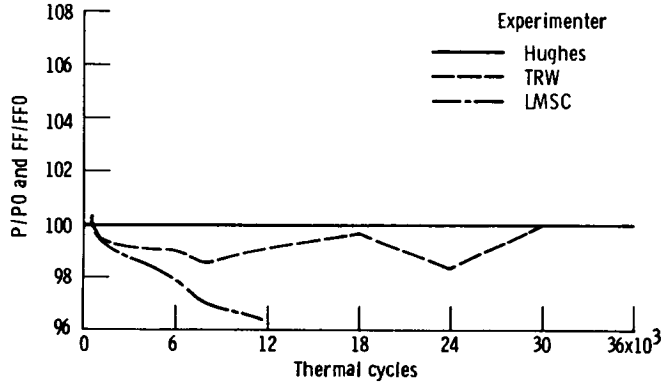

Figure 1. - Welded modules.