# Hypervelocity Impact Studies on Solar Cell Modules

## NAS3-99200

FINAL REPORT

to the

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EXECUTIVE SUMMARY

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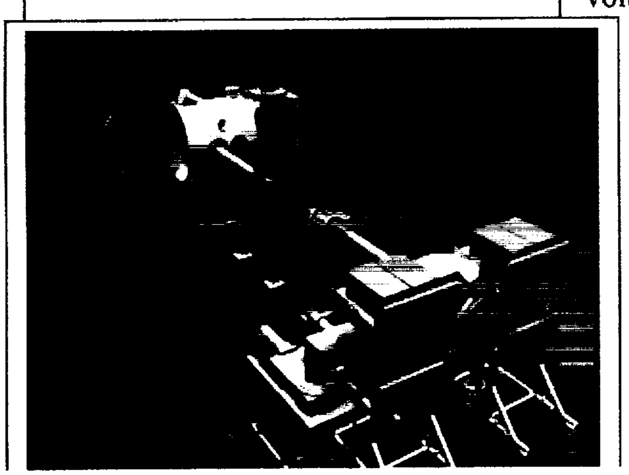
### Introduction

As the requirements for increased power and operating voltage levels for satellites have been identified, serious problems have been encountered that have resulted in the loss of power, science data and the loss of mission. These newly discovered high voltage plasma effects have resulted in significant schedule and cost "hits" to current satellites as they attempt to accommodate for these interactions with the space plasma. Thus an understanding of these effects is necessary to design reliable high voltage solar arrays of the future, especially for Space Solar Power applications. The greatest unknown is the effect of high velocity micrometeoroids on future high voltage arrays (>200V). The existing NASCAP-GEO models do not include the effects of micrometeoroid penetration. Therefore, the objective of this work is to study the effect of hypervelocity impacts on the design of high voltage solar arrays for use in GEO and/or LEO environments..

### Background:

Solar cell modules were composed of four SOA 2x4 cm GaAs solar cells with 6 mil cover glasses connected in two-cell series strings on a Kapton substrate were purchased from TECSTAR, Inc. A picture of such a module is shown in figure 1. Efficiencies were above18% except for two modules that had low efficiency strings caused by poor fill factors. These samples were certainly typical of state-of-the-art GaAs cells and modules. The samples had only limited coverglass overhang, hence the likelihood of biasing the samples to high voltages was limited.



### Facility Description

The Hypervelocity Impact Facility is shown schematically in figure 2. The gun consists of an arc discharge gun, a 5-meter flight tube and a 1-m diameter target chamber. Discharging eight capacitors that are charged to a potential of 40,000 V fires the gun. This discharge vaporizes an aluminum foil placed behind the impact particle charge. In these tests, soda lime glass particles nominally 40-120 μm in diameter were used. Approximately 40 – 70 particles will impact the target. A shutter placed in the middle of the 5-meter flight tube eliminates the low speed (<5 km/s) particles.

The target chamber is equipped with a streak camera that records particle x-y coordinates and velocities as well as observing any plasma discharges that may occur. Thus, impacting particle coordinates, size and velocity can usually be obtained. However, in these tests, the presence of arcing during impact produced additional light that usually obscured subsequent impact events. A photomultiplier tube (PMT) that imaged the test plane also observed the arcing. Although impact locations could not be determined with the tube, the signal provided timing and shape of both the impact and the arc emissions. A hollow cathode device provided by MSFC provided the plasma environment for the impact tests. Later, the cathode was damaged so tests on the ENTECH modules used a Tesla coil was used to excite an argon gas stream and provide low temperature plasma.

**Test Results**

Test 1 (SSP-1): A cell with six areas of zero coverglass overhang was selected for the initial test. The two cells in each series string were shorted together and a bias applied across them. The sample could only be biased to -200V due to interactions with the plasma. A 60V differential between the strings was established. The string arced as shown in figure 3. The voltage drops from –200V to –8.5V in 20 μsec. However, the arc appears to extinguish and the voltage begins to recover on its own. At 56 μsec after that first arc, a second arc begins at a voltage differential of –126.6V. This does not seem to be associated with any particle impact (note the particle impact about 32 μsec later). It appears that the recharging seen on the "red" curve takes a sudden increase just at the onset of the second arc, so the second arc appears to be feeding the first. The voltage on that string then continues a gradual rise back to the –200V level. The PMT trace shows that the maximum intensity of the second arc occurs precisely at the point of maximum dV/dt. It is interesting to note that the recharging of the red string as assisted by the blue string terminated when the voltage of the red string had increased to –21V and the voltage of the blue string had decreased to –87V – or at a voltage differential of 66V. The arc seemed to come from an impact on a solder connection as shown in figure 4.In this first test, a new phenomena was observed wherein a second arc, not associated with an impact event, served to partially recharge the recovery of the voltage that occurred in the first impact-related arc event.

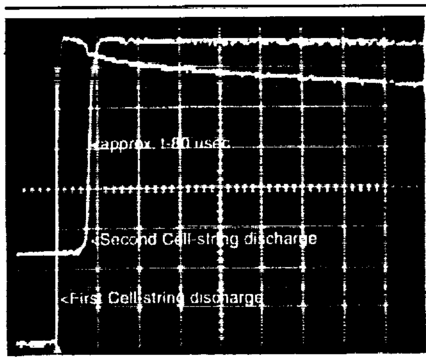



**Figure 3:** Voltage traces, red and blue strings – SSP1

**Figure 4:** Impact site on the red wire solder connection

Shot 2 (SSP-2): The sample in this test had three "zero overhang" locations. Test conditions were nominally the same as Shot 1. The hollow cathode was operated at its minimum stable operating voltage and current. The velocity of the first particle impacting the target was 10.2 km/s.

The discharge of the "Blue" string caused the voltage on that string to decay at rate and waveform shape comparable to that of the "Blue" string discharge of test SSP-1 also biased at –140 V. Despite this being the first cell string to discharge, it did so at a moderate rate unlike that of the SSP-1 test "Red" string with –200 V bias being the first discharge of that test. This may suggest that the dynamics of discharge may perhaps be potential related; i.e. moderate potentials cause gradual discharges whereas higher potentials lead to abrupt discharge rates. However, this is pure speculation at this time.

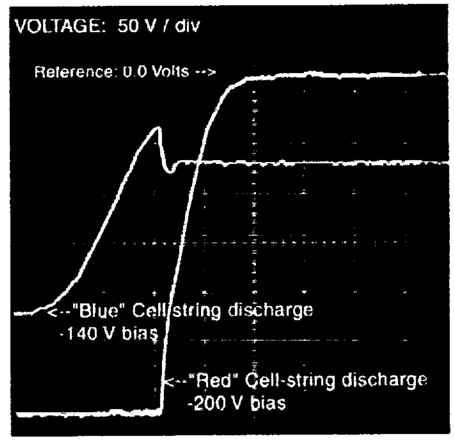



**Figure 5:** Voltage Traces for SSP-2

What may perhaps be more interesting is to examine the potential difference between the two strings during the discharge of the "Red" string. At approximately 870.8 μs, the "Blue" string potential was -31.7 V and "Red" string was –200 V, or a 168.3 V differential ("Red" over "Blue") when the discharge of the second string, the "Red" string starts. Compare this with the onset of the second discharge event of test SSP-1 of a 126.6 V differential ("Blue" over "Red"). There is indication that the discharge of current from "Red" to "Blue" string occurred that partially recharged the "Blue" string. Its voltage rapidly goes from –31.7 V to -58.3 V before this current "conduit" closes. The potential difference at the moment when this connection stops is approximately 68.3 V (126.6 to 58.3). This is very close to that of 66 V from test SSP-1 when that conduit also apparently closed. It is noted that in space, no arcing seems to occur at actual or differential biases below ~70VDC. This test had a number of similarities to the first test. The second discharge in this test of the "Red" string had a rapid rise-time comparable to that of the "Red" string of SSP-1 (see comment above about voltage magnitude). Also, note that the "Blue" string again, as in test SSP-1, holds a nearly constant voltage while the "Red" string recharges during the time the waveform data is recorded. Several minutes after the test, both strings had recovered their full initial bias potentials.

Because no higher voltages could be obtained from these GaAs samples, a test was initiated on modules provided by ENTECH, Inc. These modules consisted of a series string of Spectrolab-supplied concentrator multijunction solar cells. These cells were completely covered by a coverglass and had been hi-pot tested at ENTECH to a bias of 2250 V as shown in figure 6. This sample was placed in the Hypervelocity Impact Facility and exposed to two shots. Because of the damage to the hollow cathode, a Tesla coil was used to provide the background plasma. This plasma was an excellent simulation of a low temperature plasma. In the first shot, particle velocities were only 9.4 km/sec while in the second test a maximum of 11.6 km/sec was achieved. In the first test the sample was biased to –400 V and in the second, to –438 V. In both cases NO arcing was observed. It is important to note that in this sample, the electrical

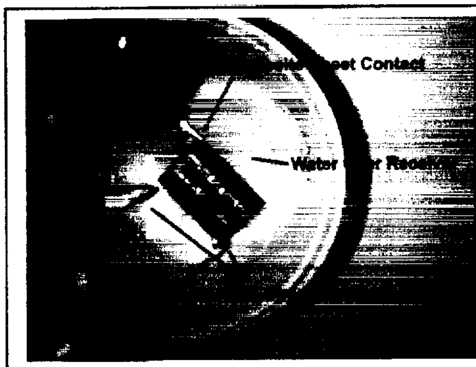


**Figure 6:** High Voltage Testing of Concentrator Cell

contacts are fully insulated from the space plasma environment. Testing at even higher voltages was suspended until a new power supply was obtained.

## Summary

Based on the testing done to date, it appears as if solar arrays with unprotected contacts are susceptible to arcing upon hypervelocity particle impacts. Although coverglasses were penetrated and other cell contacts damaged, no arcing occurred at those sites to the best of our detection ability. The GaAs samples had numerous areas where there was zero coverglass overhang, hence it was impossible to obtain bias voltages above –200 V. With larger coverglass overhang and insulation of bare interconnects it may be possible to achieve voltages near 1000V. The ENTECH samples had both cells and contact strips that were fully insulated. These samples showed no arcing upon hypervelocity particle impact at velocities as high as 11.6 km/sec and bias voltages up to –438 V. Thus it appears that these preliminary tests have uncovered basic design approaches that can lead to high voltage (>400 V and perhaps 1000 V) solar arrays

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13. ABSTRACT *(Maximum 200 words)*
Space environmental effects have caused severe problems as satellites move toward increased power and operating voltage levels. The greatest unknown, however, is the effect of high velocity micrometeoroid impacts on high voltage arrays (>200V). Understanding such impact phenomena is necessary for the design of future reliable, high voltage solar arrays, especially for Space Solar Power applications. Therefore, the objective of this work was to study the effect of hypervelocity impacts on high voltage solar arrays. Initially, state of the art, 18% efficient GaAs solar cell strings were targeted. The maximum bias voltage on a two-cell string was -200 V while the adjacent string was held at -140 V relative to the plasma potential. A hollow cathode device provided the plasma. Soda lime glass particles 40-120 µm in diameter were accelerated in the Hypervelocity Impact Facility to velocities as high as 11.6 km/sec. Coordinates and velocity were obtained for each of the ~40 particle impact sites on each shot. Arcing did occur, and both discharging and recharging of arcs between the two strings was observed. The recharging phenomena appeared to stop at ~66V string differential. No arcing was observed at -400 V on concentrator cell modules for the Stretched Lens Array.

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