Simulated Space Environmental Effects on Thin Film Solar Array Components

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Abstract

The Lightweight Integrated Solar Array and Transceiver (LISA-T) experiment consists of thin-film, low mass, low volume solar panels. Given the variety of thin solar cells and cover materials and the lack of environmental protection typically afforded by thick coverglasses, a series of tests were conducted in Marshall Space Flight Center's Space Environmental Effects Facility to evaluate the performance of these materials. Candidate thin polymeric films and nitinol wires used for deployment were also exposed. Simulated space environment exposures were selected based on SSP 30425 rev. B, "Space Station Program Natural Environment Definition for Design" or AIAA Standard S-111A-2014, "Qualification and Quality Requirements for Space Solar Cells." One set of candidate materials were exposed to 5 eV atomic oxygen and concurrent vacuum ultraviolet (VUV) radiation for low Earth orbit simulation. A second set of materials were exposed to 1 MeV electrons. A third set of samples were exposed to 50, 100, 500, and 700 keV energy protons, and a fourth set were exposed to >2,000 hours of near ultraviolet (NUV) radiation. A final set was rapidly thermal cycled between -55 and +125°C.

This test series provides data on enhanced power generation, particularly for small satellites with reduced mass and volume resources. Performance versus mass and cost per Watt is discussed.

I. Introduction

The Lightweight Integrated Solar Array and Transceiver (LISA-T) project is developing the technology for a deployable solar array that can provide over a hundred watts of power yet stow into less than a standard one-unit (1U) CubeSat, or a volume less than 4 inches x 4 inches x 4 inches (10 cm x 10 cm x 10 cm) (fig. 1). The solar cells in these arrays are flexible and, therefore, cannot be deployed with the typical, rigid coverglass and substrate materials. As a result, LISA-T uses thin, flexible polyimide materials to both support and protect the thin film cells (fig. 2). These polyimide materials and coating processes were developed by ManTech/NeXolve Corporation of Huntsville, AL. A series of simulated space environment exposures were conducted at Marshall Space Flight Center (MSFC) to evaluate the durability of these solar array materials and the performance of the solar cells. These simulations included atomic oxygen (AO), ultraviolet (UV) radiation, electron radiation, proton radiation, and thermal cycling. All of these simulations were done in high vacuum (~1 x10-6 torr).

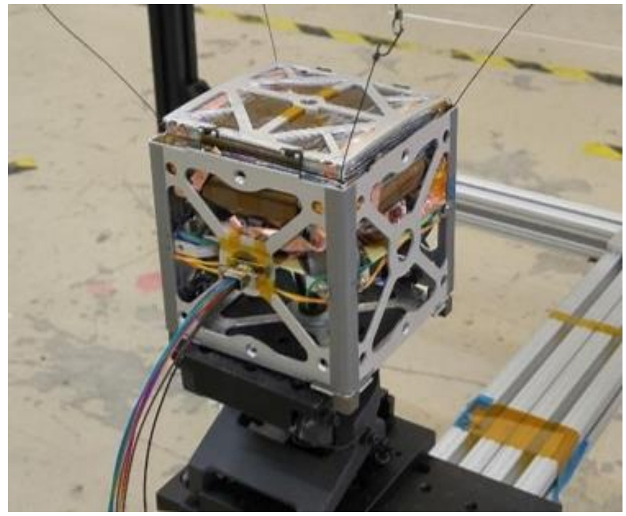

Figure 1. Stowed LISA-T solar array in 1U Cubesat

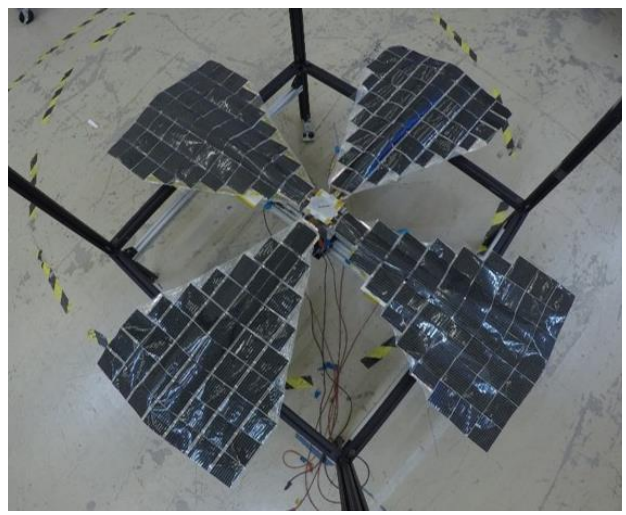

Figure 2. Deployed solar array

Three types of flexible solar cells were studied: copper indium gallium (di)selenide (CIGS), Inverted Metamorphic Multi-junction (IMM), and single junction gallium arsenide (GaAs), but not all types were in every exposure. After each iteration, the current-voltage curves were measured. Mass and optical property measurements were made when appropriate.

AO fluences and UV radiation exposures were selected based on SSP 30425 rev. B, "Space Station Program Natural Environment Definition for Design" for a six-month mission. This is a higher AO fluence than would be expected for a mission during solar minimum or in a higher orbit. Particulate radiation exposures were selected based on the American

Institute of Aeronautics and Astronautics (AIAA) Standard S-111A-2014, "Qualification and Quality Requirements for Space Solar Cells."

II. Simulated Space Environment Exposures

A. Atomic Oxygen

One bare and one CORIN-coated IMM solar cell were exposed to 5 eV neutral AO with concurrent VUV radiation in the MSFC Atomic Oxygen Beam Facility (fig. 3). Because the solar cell samples did not cover the entire beam area, small strips of candidate protective films were also exposed. These films, Optinox, Optinox with cerium oxide, CORIN, and CORIN with cerium oxide were characterized before and after exposure for mass and transmission in the UV-visible wavelengths. Small sections of nitinol wire were also exposed. In addition, a strip of Kapton, a polyimide film with known AO erosion rate was exposed to confirm the AO fluence to the samples. The IMM solar cells were exposed to a total of 2.5 x 10^{21} atoms/cm^2 of AO.

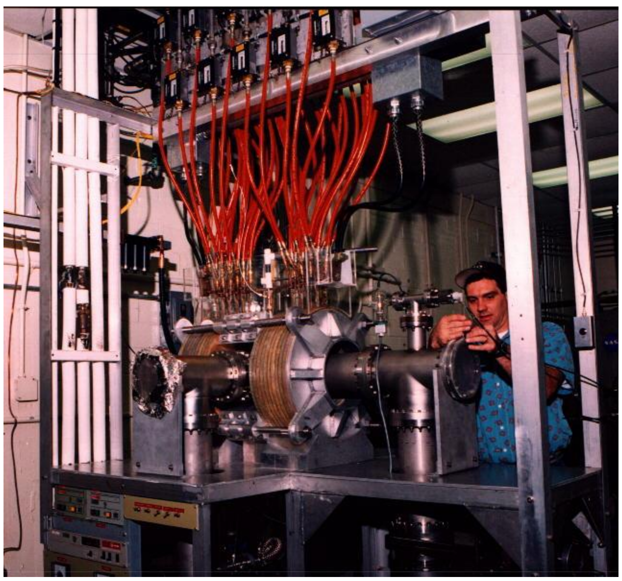

Figure 3. MSFC Atomic Oxygen Beam Facility

The results were mass loss of 1.3% and 1.9% for the bare and coated solar cells, respectively. The coated solar cell indicated a slight decrease in reflectance due to surface texturing, which in turn produced a small increase in power retention (103.6% of original). The bare solar cell maintained 97.6% power retention. Mass loss indicated that the cerium oxide did improve resistance to AO erosion but not enough for the added effort in manufacturing. CORIN shows promise as a protective coating, as it forms a self-passivating layer in AO.

Two kinds of nitinol were exposed to AO, superelastic used for the LISA-T antenna and a more pliable shape memory wire used for solar array deployment. After AO exposure, the superelastic wire notionally returned to its set shape after deformation. The more pliable wire lost 0.05% mass, measurable but not significant, and also returned to its set shape after deformation. Further characterization is needed to understand any potential physical changes which are not clearly observable.

B. Ultraviolet Radiation

Bare and coated IMM and CIGS solar cells were exposed to 2,000 equivalent sun-hours of UV (fig. 4). The source was a xenon lamp of 230 to 400 nm wavelength. The bare IMM retained 98.5% power, while the coated IMM degraded to 80.8% due to yellowing of the CORIN. Bare CIGS degraded to 70% power or less, mainly in open circuit voltage. Here, the CORIN did protect the CIGS cells, keeping the power at 86.5% through 1,578 ESH. CORIN with cerium oxide performed even better, keeping the CIGS cell power at 91.6%. Optinox has higher transmission than CORIN in the UV wavelengths and so had slightly better performance when applied to the IMM cells.

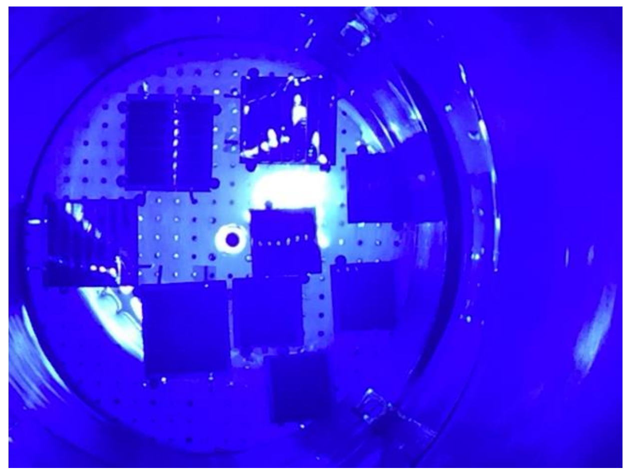

Figure 4. UV exposure of LISA-T solar cells

C. Electron Radiation

Both the electron radiation and proton radiation exposures were performed in the MSFC Combined Environmental Effects Facility (fig. 5). IMM, CIGS, and single junction GaAs solar cells were exposed to 1 MeV electrons, starting with a fluence of 3 x 10^{13} e-/cm2 and going up to 5 x 10^{15} e-/cm^2. CIGS cells demonstrated better resistance to radiation damage, maintaining power retention through all exposures. IMM cells slightly degraded after 1 x 10^{14} e-/cm^2. The single junction GaAs cells were strongly affected by the radiation exposure. Thin film samples of CORIN and CORIN with cerium oxide were exposed with the solar cells; their transmission curves were unaffected by the electrons.

Figure 5. MSFC Combined Environmental Effects Facility

D. Proton Radiation

IMM and CIGS solar cells were exposed to 50, 100, 500, and 700 keV energy protons. Bare CIGS cells degraded rapidly in 50 keV protons, while the coated solar cells maintained high power retention up to 1 x 10^{15} p+/cm^2. The CORIN appeared to protect the underlying solar cells from higher energy proton damage below 1 MeV.

E. Thermal Cycling

IMM and CIGS solar cells were subjected to rapid thermal cycling between -55 and +125 °C for 100 cycles (fig. 6). In addition, CIGS and IMM sub-coupons with solar array boom elements were cycled at least 35 times and in some cases up to 100 times. CORIN-coated CIGS samples performed well when the CORIN was applied in a liquid process. CORIN-coated CIGS samples with anti-reflection (AR) properties which were cast separately then bonded together experienced delamination due to thermal cycling. Improvements in the AR process have been developed but not yet tested. The IMM sub-coupon with boom elements passed mechanical inspection. Bare and CORIN-coated IMM strings both had one cell drop out for a power loss. IMM was not expected to degrade at this temperature, and it is likely the cells dropped out due to handling rather than thermal cycling, so this test will be repeated.

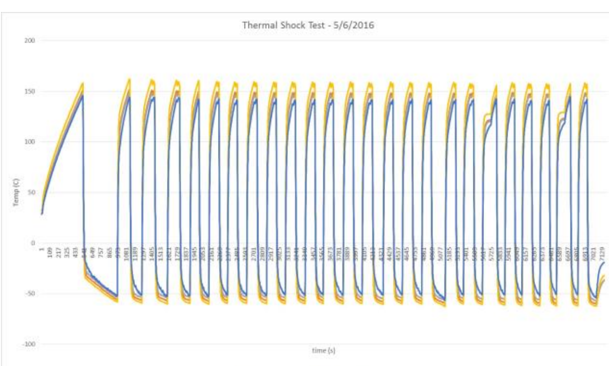

Figure 6. Thermal cycle profile of LISA-T solar cells

III. DISCUSSION

IMM technology represents a high performance, albeit higher cost, modestly lightweight, and extremely thin solar cell option. The CIGS is a low cost, albeit lower efficiency for less than half the weight of the IMM cell but twice the thickness. The single junction GaAs cells are a medium option in cost and efficiency but were dropped from the test matrix after the poor performance in electron radiation exposures.

CORIN and CORIN with cerium oxide show promise as protective coatings for both IMM and CIGS solar cells. CORIN was particularly effective in protection from AO and proton radiation damage. Optinox shows promise as a protective coating for the IMM solar cells outside of the AO environment.

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REFERENCES

SSP 30425 rev. B, "Space Station Program Natural Environment Definition for Design"

AIAA Standard S-111A-2014, "Qualification and Quality Requirements for Space Solar Cells."

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