Combined Space Environmental Exposure Tests of Multi-junction GaAs/Ge Solar Array Coupons

Bao Hoang¹, Frankie Wong¹, Ron Corey¹, George Gardiner¹, Victor V. Funderburk¹, Richard Gahart¹, Kenneth H. Wright², Todd Schneider³, and Jason Vaughn³

¹Space Systems/Loral
Palo Alto, California 94303, USA

²University of Alabama in Huntsville
Huntsville, Alabama 35899, USA

³ NASA Marshall Space Flight Center
Huntsville, Alabama 35812, USA

A set of multi-junction GaAs/Ge solar array test coupons were subjected to a sequence of 5-year increments of combined environmental exposure tests. The purpose of this test program is to understand the changes and degradation of the solar array panel components, including its ESD mitigation design features in their integrated form, after multiple years (up to 15) of simulated geosynchronous space environment. These tests consist of: UV radiation, electrostatic discharge (ESD), electron/proton particle radiation, thermal cycling, and ion thruster plume exposures. The solar radiation was produced using a Mercury-Xenon lamp with wavelengths in the UV spectrum ranging from 230 to 400 nm. The ESD test was performed in the inverted-gradient mode using a low-energy electron (2.6 – 6 keV) beam exposure. The ESD test also included a simulated panel coverglass flashover for the primary arc event. The electron/proton radiation exposure included both 1.0 MeV and 100 keV electron beams simultaneous with a 40 keV proton beam. The thermal cycling included simulated transient earth eclipse for satellites in geosynchronous orbit. With the increasing use of ion thruster engines on many satellites, the combined environmental test also included ion thruster exposure to determine whether solar array surface erosion had any impact on its performance. Before and after each increment of environmental exposures, the coupons underwent visual inspection under high power magnification and electrical tests that included characterization by LAPSS, Dark I-V, and electroluminescence. This paper discusses the test objective, test methodologies, and preliminary results after 5 years of simulated exposure.
Combined Space Environmental Exposure Tests of Multi-junction GaAs/Ge Solar Array Coupons

Bao Hoang1, Frankie Wong2, Ron Corey3, George Gardiner4, Victor V. Funderburk5, Richard Gahart1, Kenneth H. Wright5, Todd Schneider5 Jason Vaughn2
1Space Systems/Loral, 2University of Alabama in Huntsville, 3NASA Marshall Space Flight Center

Introduction

A set of multi-junction GaAs/Ge solar array test coupons were subjected to a sequence of 5-year increments of combined environmental exposure tests. The purpose of this test program is to understand the changes and degradation of the solar array panel components, including its ESD mitigation design features in their integrated form, after multiple years (up to 15) of simulated geosynchronous (GEO) space environment. These tests consist of simulated UV radiation, electrostatic discharge (ESD), electron/proton particle radiation, thermal cycling, and simulated ion thruster exposures. The solar radiation simulation was produced using a Mercury-Xenon lamp with wavelengths in the UV spectrum ranging from 200 to 400 nm. The ESD test was performed in the inverted-gradient mode using a low-energy electron (2.6 – 6 keV) beam exposure. The ESD test also included a simulated panel coverglass flashover for the primary arc event. The electron/proton radiation exposure included both 1.0 MeV and 100 keV electron beams simultaneous with a 40 keV proton beam. The thermal cycling included simulated transient earth eclipse for satellites in geosynchronous orbit. With the increasing use of ion thruster engines on many satellites, the combined environmental test also included ion thruster exposure to determine whether solar array surface erosion had any impact on its performance. Before and after each increment of environmental exposures, the coupons underwent visual inspection under high power magnification and electrical tests that included characterization by LAPSS, Dark I-V, and electroluminescence. This paper discusses the test objective, test methodologies, and preliminary results after 5 years of simulated exposure.

Test Coupon Configuration

Three test coupons are being used in this test program. Each coupon consists four (4) Emcore Advanced Trilaminate GaAs/GaSb (AT3) solar cells. The solar cell area is 30.9-cm x 30.9-cm. The coverglass is Opalite CMG coverglass, 100-μm thick with a single-layer MgF2 anti-reflective coating. Each solar cell assembly (SCA) has a discrete Silicon bypass diode. As a part of the ESD mitigation design, the cell laydown included room-temperature vaporizing (RTV) silicone adhesive grouted area between the cell parallel gaps (gaps between cell strings). The SCA interconnectors and busbars were conformal coated with RTV silicone adhesive. The small quantity of solar cells per coupon was due to the limited beam area of the Proton particle radiation. Figure 1 is a photograph of a test coupon.

Test Plan/Environments

Test Phase 1: In parallel with the coupons’ combined environmental tests, a set of solar array material coupons were subjected to combined environmental tests, at their material component level, as shown by Test Phase 1 in the test flow diagram below. Test Phase 1 is designed to generate material property data as a function of on-orbit life. Data from Test 1 are required to support simulated ion thruster erosion of solar array coupons in Test Phase 2.

Test Phase 2: After ESD and irradiation test, the coupons are then subjected to thermal cycling test. The typical thermal cycling test profiles are shown in Figure 4. It is essential for the thermal cycling profile to match the predicted rapid on-orbit thermal variation in order to properly produce the ‘aged’ condition of the solar array coupon materials. The thermal cycling test was performed in a partial vacuum condition, 3.3 – 5.3 Pascal, to facilitate the desired on-orbit thermal cycling profile. The temperature limits were 95°C +10°C/-0°C and -180°C +10°C. The target for the total number thermal cycles is 1520 which simulates earth eclipse cycles of 15-yr GEO mission. After each 5-yr increment of thermal cycling, the coupons are exposed to a simulated 5-yr SPT erosion using a Xenon ion source. The exposure time is for a given Xenon ion energy and flux is provided by test data acquired from Test Phase 1.

Test Phase 3: After the complete 15-yr combined environmental exposures, the coupons are subjected to EOL ESD and ESD/SPT interaction tests. The purpose of the ESD/SPT interaction test is to evaluate if the presence of an SPT pattern can induce an ESD sustained arc. With the exception of Test Phase 1 material erosion tests, all of the environmental exposures tests are being performed in the NASA Marshall Space Flight Center test facilities.

Experimental Results

To date, with the exception of the simulated SPT erosion test, the Loral/NASA team has completed 5 years of combined environmental exposures to the three solar array test coupons. Detailed inspection showed slight coloration (yellowing) of the ETFE wires. Note that the Proton beam size was approximately 127 mm in diameter; therefore, none of the Proton beam exposure reached the ETFE wires. However, the key area of interest is the RTV grouted area between the solar cells. After thermal cycling, the S-691 RTV adhesive grout shows hairline cracks in several locations, as shown by the close-up view in Figure 5. The condition is believed to be caused by embrittlement of the RTV adhesive due to the combined irradiation and the thermal cycling exposures. The coupons, however, successfully passed a partial ESD test post 5-years of combined environmental exposures (the ion erosion component has not been performed yet). During the ESD test, the ESD primary arc threshold voltage was observed to decrease from 2900V to 200V. More details of these findings are presented in reference [3]. Figure 6 shows the solar array coupon #10 LAPSS I-V characteristics to date.

Summary

A combined environmental test program of solar array coupons is ongoing. Test results post 10-year and post 15-year aging are scheduled for completion in the first and second quarter 2011, respectively. Initial test results for post 5-year aging show degradation of solar array materials (e.g., hairline cracks in the coupon RTV adhesives) not shown by previous qualification tests in which thermal cycling was the only environmental exposure. This combined environmental test program has further shown a renewed emphasis in understanding space material properties as a function of on-orbit life and their effects to the solar array design and performance.

References