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Development and testing of solar panels for small satellite applications at CNEA

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ABSTRACT

This paper presents the activities performed by the Solar Energy Department of the Argentinean Commission for Atomic Energy related with the manufacturing, qualification and testing of solar panels for small satellites mission. In particular, the complete process of solar panel integration is described and also the techniques of mechanical inspection and power generation, in order to assess the solar panels quality, are presented. Finally telemetry data of power generation from the last space missions Nu-Sat 1&2 of Satellogic Corp. (our main customer) are analyzed and conclusions are presented.

INTRODUCTION

The Solar Energy Department (DES) of the Argentine National Atomic Energy Commission (CNEA) performs research and development activities related to the use of photovoltaic (PV) solar energy conversion for space and terrestrial applications. Since March 2001, the DES, sited at Constituyentes Atomic Center (CAC) from CNEA, has been working on the development of solar arrays for satellite missions in the frame of the national space plan [1]. Part of this plan has involved the AQUARIUS/SAC-D mission, a successful joint venture between NASA and CONAE space agencies, in which solar panels were developed at DES. Nowadays the SAOCOM project (a mission in collaboration with the Italian Space Agency) solar panels are being manufactured at CNEA lab. Another activity related to space applications involves the development of solar arrays for small satellites for industry.

This work presents the activities related with the integration and testing of PV modules for small space missions at CNEA solar panel integration lab. In particular, a series of six small PV panels integration has been done at CNEA facilities for industry and the "in flight" orbital telemetry has indicated a good behavior of the panels in the different cube-sats and bug-sats satellite missions. The activities involve the individual I-V (voltage vs. current curve) cell measurement, classification of cells by short circuit current in order to match them in the cell strings, the soldering process for string elaboration, visual inspection of cells, the bounding process of the cell strings on the panel substrate and finally the wiring and soldering between components.

For the testing stage, the electrical measurements for power generation tests through multiflash technique are shown and visual inspection of cells through electro-luminescence in order to detect small cracking at the cells are also shown. Furthermore radiation damage tests at "TANDAR" particle accelerator with triple junction solar cells are described. At last, data telemetry of the solar arrays generation during the orbit is shown and conclusions are presented.

INTEGRATION ACTIVITIES

The following section shows the different stages during the integration process of solar panels al CNEA Lab. The DES integration laboratory (called Lab from now) consists in a class 10.000 clean room and is about 200m2 area. [2, 3]

The solar cells used for solar panels elaboration at DES are triple junction high efficiency solar cells based on III-V materials. In particular the cells used for both, traditional mission and small satellites are about 30% efficiency InGaP/GaAs/Ge monolítical structure solar cells [4]. The first step in the solar panel manufacturing process is the classification of cells in order to match them by short-circuit current for cell string elaboration. In this way, the first activity consists in the individual I-V curve (current vs. voltage) measurement of each CIC solar cell (CIC solar cell means Covered and Interconnected Cell and includes the metallic interconnectors soldered at the top of the cell plus the cover glass bounded at the front). For this purpose, a close match AM0 solar simulator class AAA is used (TSpace Systems Corp.) which provides an adequate intensity and spectrum as standard test condition suggest. (Intensity1367W/m^2, spectrum AM0 and 28°C solar cell temperature)

Figure 1: Measurement of the I-V curve of individual CIC solar cell under standard test conditions are performed using a close match AM0 solar simulator.

Once the totality of solar cells were measured, the next stage is the cell string elaboration, which involves the soldering between six CIC cells and the bypass diode for each cell too. Fig. 2 shows the process of soldering in the back-contact of the CIC.

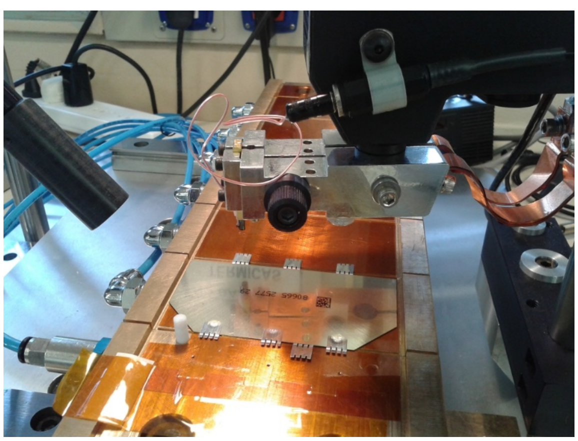

Fig 2. Soldering process of interconnectors on the back-contact of the CIC solar cell.

Before the bounding of the cell strings on the panel substrate (the panel substrate consist of a thin aluminum base with Kapton® isolation and copper printed circuits as electric connections) a previous electrical measurement of the I-V curve of the string is performed. This measurement is carry out thought multiflash method [5, 6] explained in detail in the next section. Furthermore, previous to the bounding of strings to the substrate and in order to protect the cells, the complete wiring process is carried out. The bounding process itself is made using RBT component and slotted masks with the solar cell shape in order to avoid air bubbles. Fig 3 shows the two processes recently mentioned at CNEA lab.

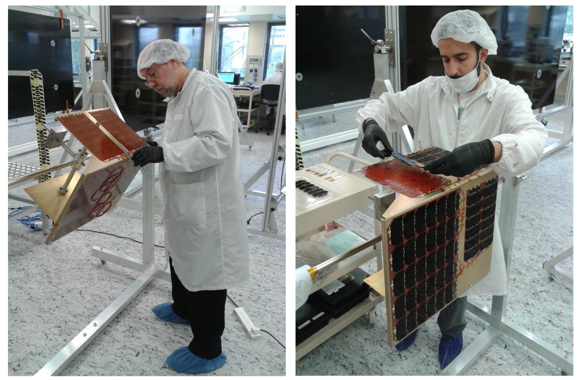

Fig 3. Cabling and string cell bounding process are shown

SOLAR PANEL TESTING

Once the cell string is completed, two test to secure quality are performed: electrical and mechanical inspection tests. Electrical test verifies that solar cells were not degraded basically during the soldering process. For this purpose, the multi-flash method [5,6] is used with a commercial Xe flash lamp. In this method one flash of the lamp means one I-V point of the curve for each load condition, for short-circuit to open circuit in discrete steps. A calibrated reference solar cell is used to monitor an intensity of 1367W/m^2 on the test plane. Figure 4 shows the I-V obtained by this method for two different strings and reflects an expected shape of this characteristic. This test is made before and after cell strings are attached to the substrate.

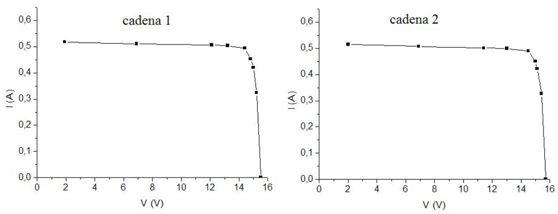

Figure 4. Typical IV curve of six-cell string using multi-flash method.

Another verification to ensure the solar panel quality is the mechanical inspection of cells through electro-luminescence technique in order to detect small cracking in the cells. This technique consist in the inspection of cells using a video camera which detects the light emitted by the middle subcell at about 800nm (cells are triple junction InGaP/GaAs/Ge) when the string is biased by a 100mA DC current. An infrared-pass filter inside the camera blocks the visible light ensuring the image to be composed only with the cell´s emitted light. Also the distance between the camera and cells and the focal length of the system allows to observe the cells more clearly than naked eye. Figure 6 shows the setup used to perform the mechanical inspection and figure 5 shows small crackings detected trough this method in several solar cells.

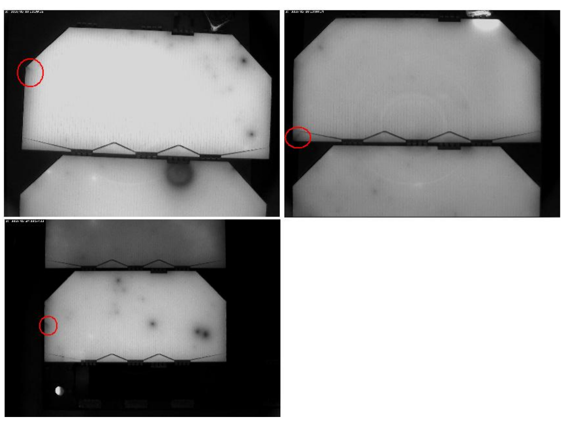

Fig 5. Small crackings at the cells are detected trough E.L. technique. The size of the cracks in these cases presented not represents a risk for the solar module

Figure 6. Setup for mechanical inspection of cells trough E.L. The camera capts the light emitted by the GaAs subcell (about 800nm) and the image is evaluated with a good detail in the monitor.

RADIATION DAMAGE FACILITIES

Solar cells and other semiconductor devices used in space applications suffer permanent degradation due to the space radiation environment, which affects both electric and electronic parameters, reducing eventually the in-orbit lifetime. The most important effect of radiation on solar cells is the accumulation of damage in the semiconductor lattice, the so called TID (Total Ionising Dose).

To test and characterize the response of semiconductors devices to radiation exposure we used a beam line of our tandem Van de Graaff heavy ion accelerator (TANDAR). A special chamber design to simulate space environment allows to perform experiments under high vacuum condition and to keep the sample at controlled temperature between -120° C and +200° C during irradiation. 10 MeV proton beam was used to simulate space irradiation and the fluence was selected to represent the conditions during a space mission in a LEO during 8 years. The setup for irradiation and chamber is shown in fig 7.

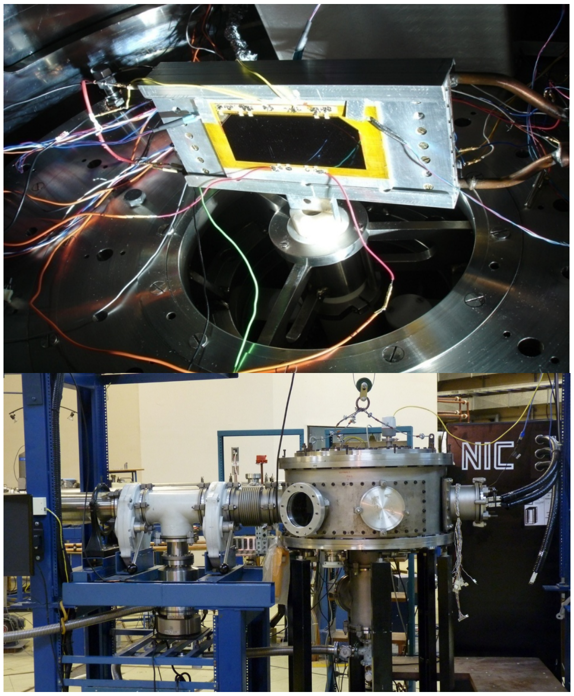

Figure 7. Setup for cell irradation and chamber

In order to study the degradation of the electrical characteristics of triple junction solar cells, the light I-V measurements were performed in situ before and after the experiment using a solar simulator with AM0 filter coupled to the irradiation chamber through a borosilicate window. The results are presented in Fig 8.

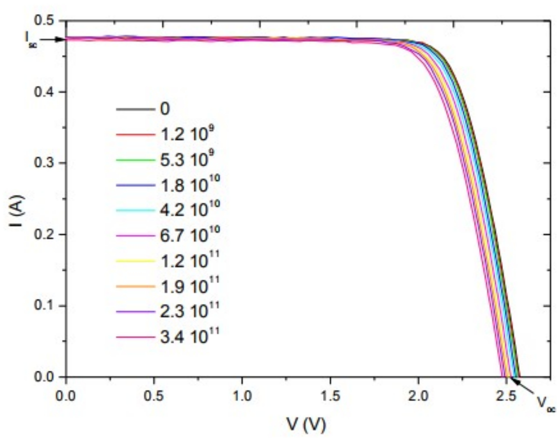

Fig 8. I-V curves of a commercial triple junction cell measured in-situ during a radiation damage test. The fluences specified are in protons/cm^2

IN FLIGHT DATA TELEMETRY

In this section we study the performance of the power system of Nu-Sat 1 which is "four face solar panels" topology in which three faces can be illuminated by the sun at the same time. The satellite power system is shown in fig 9 and consists of two faces with seven strings each (panel Y and Z in the same figure), and two faces with four strings each called +X and –X respectively. The panel Z in fig 7 is at the top of the configuration. The strings are six cells connected in serial mode and the system voltage at maximum power point is 14,5V. Total power installed in the four faces is about 145W but the theoretical maximum generation is about 70W without considering terrestrial albedo effects. Figure 10 shows the power generation of the four panels during two consecutive orbital periods and the individual shape is modulated by the relative position of each module with respect to the sun due to the orbital translation and the proper rotation of the satellite. The sum of the four generations profiles gives the total power during the orbit and their average power is near 30W. The ratio of the average power with respect with the total power installed gives a value of 0.2 which is typical of this type of "four face" power system.

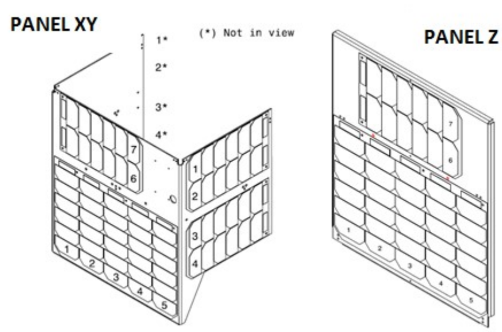

Fig 9. Topology of the Nu-Sat 1 power system

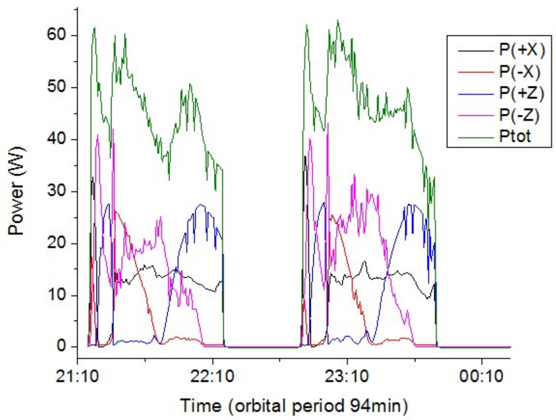

Fig 10. Solar panels power profile during two consecutive periods from in-flight data telemetry

CONCLUSIONS

This work had presented the activities related with the electrical integration, qualification and testing of solar panels at DES-CNEA in Argentina. The previous experience in large satellite mission like Aquarius/SAC-D and SAOCOM had paved the way to elaborate small sats solar panels. The full process of electrical integration of components were shown as same as the tests performed in order to asses quality. At the moment, the five previous missions with Satellogic Corp. were success and the results aim for future challenges missions. Finally power generation profile obtained from data telemetry was shown and indicated a good performance of the power system in Nu-Sat 1 and 2 space missions.

References

1. M. Alurralde et al., "Development of solar arrays for argentine satellite missions," Aerospace Science and Technology, vol. 26, pp. 38–52, (2013).

2. ISO 14644-1, Cleanrooms and associated controlled environments—Part 1: Classification of air cleanliness

3. FED-STD-209D, Federal Standard: Airborne Particulate Cleanliness Classes In Cleanrooms And Clean Zones (15 Jun 1988) [S/S BY ISO14644-1 and ISO14644-2]

4 http://www.nrel.gov/ncpv/images/efficiency_chart.jpg

5. "Spectral and dynamical study of III-V triple junction solar cells and the application to multiflash I-V measurement", H. Socolovsky, E. Yaccuzzi, J. Plá, Progress in Photovoltaics: Research and Applications 23, 1330 (2015).

6. C. Dominguez, I. Antón, G. Sala. Multijunction solar cell model for translating I-V characteristics as a function of irradiance, spectrum, and cell temperature. Progress in Photovoltaics: Research and Applications 18, 272 (2010)

7 M. Alurralde et al., "Flight model for the Aquarius/SAC-D satellite mission" 24th European Photovoltaic Solar Energy Conference, 21-25 September 2009, Hamburg, Germany