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Technological facilities for development, fabrication, integration and testing of solar arrays for space applications

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ABSTRACT

The Solar Energy Department (DES) of the Argentine National Atomic Energy Commission (CNEA) performs R&D activities related with photovoltaic solar energy conversion for space and terrestrial applications.

Sensors and solar cells have been integrated into several Argentine Satellite Missions, for ex. SAC-A satellite, SAC-D and actually SAOCOM 1A and 1B missions. Several Argentinian small satellites have being developed by Satellogic -a private company-. The solar array of Cubebug-1, Cubebug-2, BugSat- 1, NewSat-1 and NewSat-2 have been integrated with commercial ATJ solar cells at CNEA labs. This paper describes the technological facilities for the development, fabrication, integration and testing of solar arrays for space applications at DES-CNEA labs. It should be remarked that NASA and ESA documents have been taken as references for these developments .

Relevant issues such as, solar cells and diodes characterization, set up of soldering and bonding processes, radiation damage and development of testing techniques, are presented. The DES activities on flight components carried out in two clean rooms - Class 10,000 and Class 100,000 and a specialist electronics lab. Other development work are carried out in different facilities belonging to the Tandar Accelerator Laboratory, CNEA.

In space applications solar cells are protected by coverglasses from UV exposure and from low energy charged particles. An activities related to bonding techniques are development. These are bonding coverglasses to cells, bonding stringed cells to substrate, bonding buses to substrate, bonding cables and electronic devices to substrate.

INTRODUCTION

By the end of 1995, the Solar Energy Department (DES) of the National Atomic Energy Commission (CNEA) began activities related with solar cells and solar arrays for space applications. To this end, CNEA and the National Commission for Space Activities (CONAE) signed a cooperation agreement which led to a first experiment: Argentine Solar Cells in Space, on board of the Argentine satellite SAC-A (Satellite for Scientific Applications – A) launched by the end of 1998 [1].

In this article, we describe the technological facilities for development, fabrication, integration and testing of solar arrays for space applications. Particularly, the integration and testing of two engineering models are shown. It should be remarked that NASA and ESA (European Space Agency) documents have been taken as references for these developments [2,3] .

DEVELOPMENT ACTIVITIES

In DES-CNEA from the first agreements with CONAE began to work on the development and qualification of the different procedures for the integration of cells and solar panels for use in space missions. Focusing on such developments for the orbits required by the SAOCOM and SAC-D missions.

Task to date include:

- assembly of the integration and test laboratory,
- theoretical analysis and ground testing of radiation damage on solar cells,
- manufacture and testing of interconnectors,
- setting-up of the welding processes and corresponding test techniques,
- development of glass bonding techniques on cells and cells on substrate,
- design of the electrical circuit of the panels and their interconnection to the satellite,
- estimation of the energy generated by the solar panels during the space mission, in End of Life (EOL),
- development of solar radiation sensors,
- manufacture of engineering panels for conducting qualification tests on Earth,
- integration of flight panels,
- development of equipment and methods for electrical verification and visual inspection in our laboratories and in the qualification and flight campaigns of the panels,
- development of thermal cycling cameras,
- electrical, mechanical and thermo vacuum tests on the different components and on the engineering and flight panels and,
- design, manufacture, characterization and testing of Coarse sun sensors crystalline Si-based.

INTEGRATION LABORATORY

The integration of solar panels for space uses can be summarized in the following processes:

- visual inspection of the solar cells,
- welding of interconnectors to the front face of the cells,
- bonding of glass to the front face of the cells,
- measurement of the I-V curve and classification of the solar cells,
- formation of strings of cells in series,
- panel electrical wiring,
- bonding the sub string cell to the substrate and interconnection to wiring,
- electrical tests and final checks.

These processes are performed in a laboratory mounted specifically for this purpose, located in TANDAR building of the CNEA-CAC. The laboratory itself (see Figure 1) has an approximately 200 square meters and has with two entry / exit areas for staff and inputs / outputs. The whole sector is conditioned as a Clean Area Class 10,000 (ISO 7 according to FED-STD-209D) with temperature and humidity controlled. The department also has another Clean Room Class 100.00 (ISO 8 according to FED-STD-209D) and a specialized electronics laboratory. Other development work has been carried out in different facilities belonging to the Tandar Accelerator Laboratory, CNEA.

Figure 1: Solar Array Integration Laboratory, Clean Room Class 10,000.

Visual inspection

The method of visual inspection developed on the basis of the work of C. G. Zimmermann, 2006, allows by electro-optical methods the safest detection of cracks [4]. As described in the above mentioned reference, each of the sub cells making up the ATJ solar cell being directly polarized emits electromagnetic radiation at well-determined intervals as explained in the previous section. In particular, for the detection of cracks, the spectrum emitted by the intermediate cell (InGaAs) is at 879 nm.

In order to obtain the images, a commercial surveillance camera with the possibility of "night vision" was used, this camera compared to the one used originally in the work of Zimmermann or those normally used in laboratories has a cost 10 times lower although the characteristics they are similar. In this particular case, the TCM-5311 camera was used with the following technical characteristics:

- 4.8 x 3.8 mm CCD sensor

- Resolution 1280 x 960 at 15 fps

- Sensitivity range in IR 700- 1100 nm

The chamber was used for detection of cracks in individual cells and in substrings of cells soldered in series. For this, a support was designed and built that allows to vary the distance between camera and cells and a movement in two dimensions for the cells in order to be able to visualize the different zones in case the image is not complete or need to approach the camera (Figure 2).

Figure 2: Visual inspection equipment by the electroluminescence method.

Welding and soldering processes

The welding for solar cells interconnection must guarantee an adequate electrical contact and enough strength to resist the stresses commonly produced at the launch and during in-orbit operation (Figure 3a).

The resistance, parallel-gap welding technique was selected for welding the silver plated Kovar interconnectors to the front side of ATJ Emcore solar cells ([5]-[10]). The system used for welding consisted of a programmable DC power supply Model DC 25) and a parallel-gap welding head (Model 86A/EZ) made by Unitek Co (Fig. 3a). It allows programming the welding cycles, number of pulses, pulse amplitude, pulse time, modes of current flow, weld force, magnitude/time, etc. Optimum process parameters were identified in order to both, assuring stable welding conditions, and producing joints of high integrity. Previously to welding the surface condition of contacts was checked.

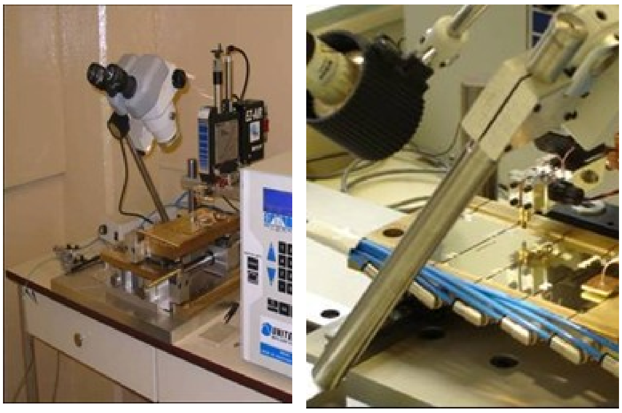
Pull tests at 45º angle were performed for assessing welding quality and strength. All tests were carried out using a small motor driven machine specifically designed and constructed with this purpose. In the case of the 45º tests all pulling strength results satisfied a requirement of 350 g established in this laboratory.

To allow comparison with data supplied by Emcore, welding pull tests were conducted at 0° pull angle.

Soldering is a reliable, established process, which has been successfully used well for past arrays [7]. For this work, it was verified that the welding made to the smoother cell contact surfaces were very much stronger than those made to the rougher back side cell surface. Moreover, measurements showed that the roughness of the back side of the cell is almost five times greater than that of the front side. It was proved that higher electrode pressures somewhat improves welding strength; however, the presence of the coverglasses adhesive hinders the increase of that pressure. Because of this, soldering was chosen for the interconnections on the back side (Figure 3b).

The joints were made with a programmable reflow Unitek system with controlled temperature profile and solder preforms consisting of a Sn/Pb/Ag alloy. The principal parameters of the system were thermode type and force, temperature and time.

The quality of welding and soldering processes was assured by verifying the actual power or temperature profiles during the processes, and through periodic pulling tests and visual inspection of imprints.



(a) (b)

Figure 3. (a) Welding system. (b) Soldering process.

Bonding process

Solar cells in space applications are protected by coverglasses from UV exposure and from low energy charged particles. A 100 μm coverglass is mounted onto each cell.

The bonding techniques can be listed as:

- bonding coverglasses to cells
- bonding stringed cells to substrate
- bonding buses to substrate
- bonding cables and electronic devices to substrate

Methods, devices and procedures must be highly reliable. To bond coverglasses, a special system was developed, consisting of: an adhesive distributor pneumatically controlled (Figure 4), a motorized electronic controlled device for horizontal motion, and a device for positioning and aligning the coverglasses on the cells.

Substrings of cells are bonded to the substrate using specially designed masks and adhesive dispensers. In all cases space qualified adhesives were used. (Figure 5)

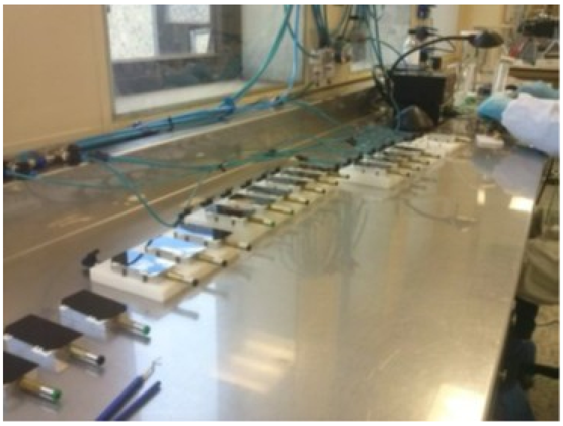


Figure 4. Adhesive applicator on the cell

Figure 5. Substrings of cells are bonded to the SAC-D substrate.

TEST PROCEDURES

Functional electrical test

For electrical characterization, DES has four measuring systems:

- multiflash technique (Figure 6 and Figure 7);
- a simple solar simulator based on a 1 kW Xe, Sciencetech SS 1kW, AM1.5 or AM0, adjusted to deliver a radiation intensity equivalent to 1 kW/m^2 or 1.367 kW/m^2 (Figure 8);
- a TS-Space “Close-match” high fidelity steady-state solar simulator with AM0 spectrum and normalized equivalent irradiance to 1367 W/m^2 and electronic data acquisition system development by DES (Figure 9), and
- a large area pulsed solar simulator.

Figure 6. Multiflash technique on modules.

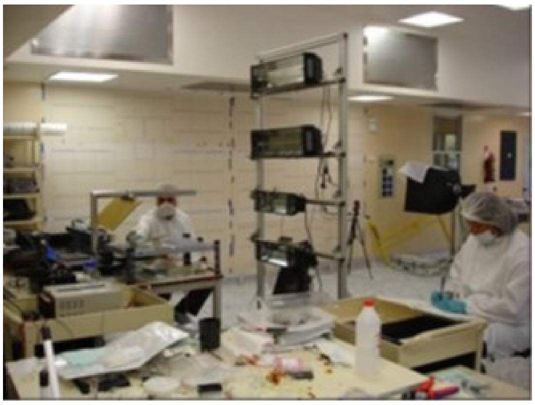


Figure 7. Multiflash technique on substrings.

Figure 8. Simple solar simulator based on a 1 kW Xe.

Figure 9. TS-Space Close Match solar simulator.

Each solar cell assembly (SCA) was electrically measured using a TS-Space Close Match solar simulator at T = 28 ºC and with 1.367 kW/m2 (equivalent to AM0 irradiation). According to the data obtained the SCA´s were classified on the maximum-power basis. Substrings of cells each were soldered and interconnected through a bus architecture. The arrangement matches the requirement of the solar array design for the specific mission (SAC-D, SAOCOM, Small Satellites, etc.

At the end of the integration of the panels, the Functional Electrical Test (FET) of each module determining the I-V curve by a source Xe pulsed light (a commercial flash), neutral filters, a digital oscilloscope and a load Electronics [11]. Measurements are made at room temperature (T = 22.5 °C ± 1 ° C), obtaining about ten I-V points between V_{oc} and I_{sc}.

Radiation damage and thermo vacuum tests

A satellite in a low Earth orbit (LEO) works in a radiation “unfriendly” environment. Inside the inner Van Allen belt there exists isotropic proton and electron irradiation, but most part of the damage is due to protons with energies ranging from a few keV to hundreds of MeV. In addition the satellite is unprotected from cosmic radiation hitting with all kinds of energetic ions.

To consider this situation a chamber was built for testing solar cells and sensors by cycling the temperature of sample coupons within the expected in-orbit temperature range. At the same time the cells under test are irradiated by a proton beam featuring a space-like spectrum with variable incidence angles to approach the isotropic space flux. Ion beams are delivered to the test chamber by the Tandar 20 MV Tandem Van de Graaff Accelerator. This facility is somewhat similar to that described in Ref. [12], but our upper energy limit for protons is at present 25 MeV, suitable for irradiating samples with 100 to 150 μm thick cover glasses. Attached to the chamber a solar simulator based on a 1 kW Xe lamp (Sciencetech SS 1kW) allows illuminating the samples with a space-like photon flux.

Figure 10 shows a picture of the facility. The size of the access lid (on top of the chamber) is 760 mm in diameter, while the ion beam enters through a 5” diameter port. The ion optics was designed to produce an ion beam of about this size on the target holder. Appropriate shielding collimators were installed to prevent nuclear reaction activation of the stainless steel beam line. The chamber can be lined with aluminum sheet with the same purpose. Some new features have been added, for example the beam line was modified to include a proton energy degrading system. This degrader allows fast modification of the beam energy in order to simulate the space proton spectrum, and also, it allows defocusing the beam to produce irradiation over bigger areas.

Figure 10: 76-cm vacuum chamber installed on one of the Tandar accelerator beam lines.

The DES also has a camera that allows thermal cycling between -70ºC and +100ºC on flight components (Figure 11).

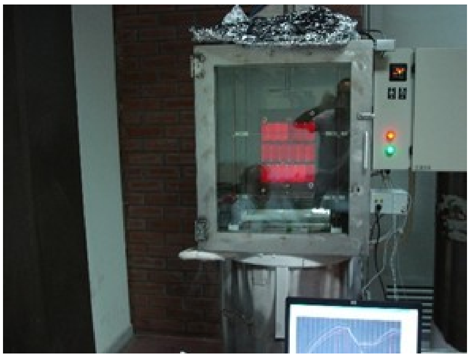


Figure 11: Thermal chamber installed on one of the auxiliary labs.

Conclusions

The Solar Energy Department has the first laboratory suitable for panel integration and tests for space missions, located in the technological facilities of the National Atomic Energy Commission at Constituyentes Atomic Center. Important progress was made in the development of the processes of manufacture and characterization of solar panels and coarse sun sensors for satellite applications, which allowed the success of different satellite missions, in terms of power supply.

This integration laboratory has the appropriate technology for the realization of the different steps of manufacturing, controls, inspections and diverse tests that allow to have in the country products of high technology tested and qualified in the space

Acknowledgments

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