

Fast Ambient Pressure Thermal cycling of space solar array samples under equivalent AM0 illumination conditions

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Abstract — This paper describes the process for the design, development, manufacturing and verification of a solar simulator to be integrated in the fast ambient pressure facilities available at ESTEC's solar generator laboratory. The development of this solar simulator facility (SCID; solar cell illumination device) responds to ESTEC request to perform ambient pressure thermal cycling on solar array samples, based on triple junction solar cell technologies, under AM0 equivalent illumination during the hot part of the cycle. The SCID facilities were developed, manufactured and tested by CSL, Centre Spatiale de Liege [Belgium].

Fast thermal cycling facilities allow to perform full nominal mission life plus margins, in a reasonable amount of time, for LEO and MEO missions. The solar simulator concept designed and manufactured for the simulation of AM0 equivalent illumination and implemented in the SCID facility is presented (i.e. array of halogen and selective band LEDs) and its suitability to simulate the operation of solar cells under full representative AM0 spectral conditions is discussed. The solar simulators have been designed to provide from 1 solar constant up to 5 solar constants, with an uniformity better than $\pm 10\%$. The paper also presents the successful results of the acceptance tests performed with these SCID facilities together with the available fast ambient pressure thermal cycling chambers. These results demonstrated the robustness of the solar simulator concept to cope with the extreme temperatures during cycling and the relatively demanding pressure transients during transition between temperature extremes. Stable performance of the SCID halogen lamps and LEDs was verified during cycling as the SCID system keeps close control on their operational temperature.

Index Terms — triple junction solar cells, photovoltaic assembly, thermal cycling, illumination.

I. INTRODUCTION

Solar arrays are typically exposed in orbit to extreme thermal conditions due to eclipses. Thermal cycling test are therefore performed on space solar array samples to verify the components integration stability over the mission duration. Thermal cycling chambers typically expose samples to temperature extreme variations in dark conditions. A more representative simulation of the real environment in orbit is to illuminate the sample during the hot part of the cycle, with AM0 equivalent light. VIRAC facility (i.e. a thermal vacuum chamber together with an external solar simulator) was developed for thermal cycling in vacuum under AM0 illumination by ESTEC's Mechanical Systems and Solar

Generator Laboratories [1] for testing small solar cell samples. In order to test fully flight representative solar array samples, with an statistically sound number of solar cells, and to complete LEO or MEO mission environments, fast ambient pressure thermal cycling facilities with equivalent AM0 illumination solar simulators (SCIDs facilities designed, developed and tested by CSL) are operational at ESTEC. These facilities will considerably reduce the duration of these test programs.

II. FAST AMBIENT PRESSURE THERMAL CYCLING FACILITIES DESCRIPTION

Fast ambient pressure thermal cycling chambers are operational at ESTEC's solar generator laboratory since the 1980's. The facility operation concept is based on the circulation of inert gas flow over the solar array samples or any other kind of samples (i.e. mechanical, structural, PCBs, sample materials, .. etc). These samples are installed, typically in vertical position and parallel to the gas flow, inside the called test chamber compartment. This test chamber is connected by a flap system to a cold and hot chambers. Cold chambers have heat exchangers feed with liquid nitrogen and hot chambers have heat exchangers based on heaters. Cycles are performed communicating the hot and cold chambers with the test chamber alternatively. The performance of these facilities in terms of spatial uniformity are in the range of $\pm 5^\circ\text{C}$, for temperature extreme limits between $+350^\circ\text{C}$ and -180°C and in terms of transient temperature speed around 0°C , between 5 to 20°C/s . The facilities are able to perform under these conditions and performances up to 250 LEO thermal cycles per day.

III. SCID SOLAR SIMULATOR OPTICAL DESIGN CONCEPT DESCRIPTION

The solar simulator illumination source of the SCID is based on an array of halogen lamps and LEDs. The combination of these light sources provide the energy per spectral band required for triple junction solar cells to operate under AM0 illumination conditions. The halogen, white and Near-IR LEDs spectrums are presented in Fig. 1, together with the AM0 spectrum and the typical spectral response of a

triple junction solar cell. The triple junction solar cell electrically operates under this spectrum in the same way as under AM0 spectral conditions, because the total energy per spectral region (for each of the triple solar cell junctions) is set in the SCID light sources to be the same. This correspondence between the cell operation under AM0 illumination conditions and under other light sources, with different spectrum than AM0, is implicit in the error mismatch computation methods, where the electrical performance parameters of the measured cells under simulated light is corrected to AM0 equivalent illumination conditions [2],[3]. Therefore it is essential to calibrated the SCIDs simulators light intensity with component cells of the same type (i.e. same spectral response) of the triple junction solar cells under test.

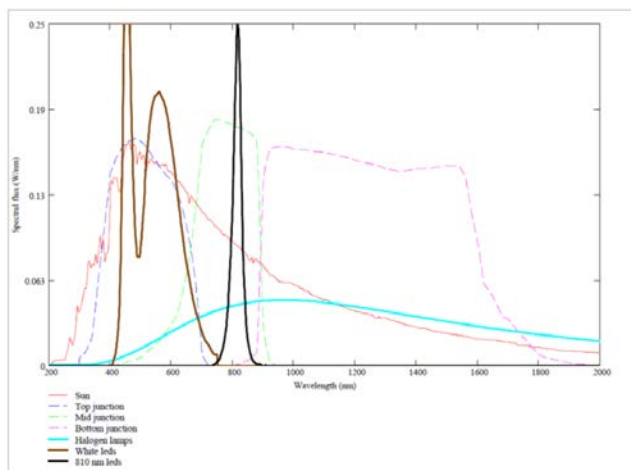


Fig. 1: AM0 spectrum, Halogen and White/IR LEDs spectrum and 3J cell spectral response.

SCIDs simulators use two different types of LEDs: White LEDs providing illumination in the spectral range between 400 and 700 nm and Near-IR LEDs providing narrow band illumination, peaking at 850nm. The halogen lamps and LEDs are distributed into an array configuration in order to improve the resulting light homogeneity over the test specimen. According to optical simulations the illumination uniformity of the SCIDs over the solar cell samples was predicted to be in the range of 11% (see Fig. 2).

The illumination intensity can be adjusted from 1 S.C. Solar Constant (1367 W/m^2) up to 5 S.C. and the illumination intensity of the halogen lamps and LEDs can be adjusted independently.

The distance between the SCIDs solar simulators and the test specimen is between 3 to 5 cm, therefore a maximum of two test specimens (solar cell sample devices like photovoltaic assembly coupons) can be tested in ESTEC facilities, one of them under illumination and the other tested under forward bias current conditions in darkness.

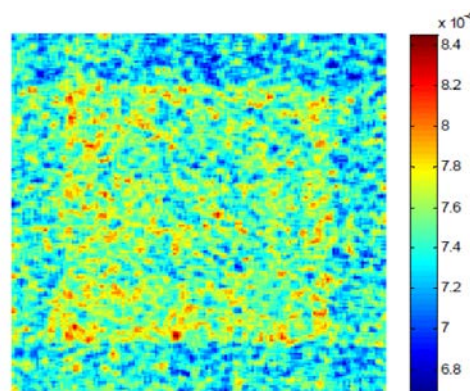


Fig 2. Simulation of SCID illumination uniformity mapping.

IV. SCID SOLAR SIMULATOR MECHANICAL AND ELECTRICAL DESIGN CONCEPT DESCRIPTION

One of the main challenges of SCID solar simulators is to perform nominally inside these fast ambient pressure thermal cycling facilities (i.e. being exposed to the same environment of the test samples), therefore the lamps are isolated from the cold/hot inert gas flow by means of a stainless steel housing and a quartz window. Heat and cold are extracted from the housing by means of coolant liquid system, embedded in the lamp/LEDs base plate, connected to adequate chillers and by constant flow of inert gas at low temperature over the lamps and LEDs. The pressure inside the housing is also monitored and relief valves prevent overpressures.

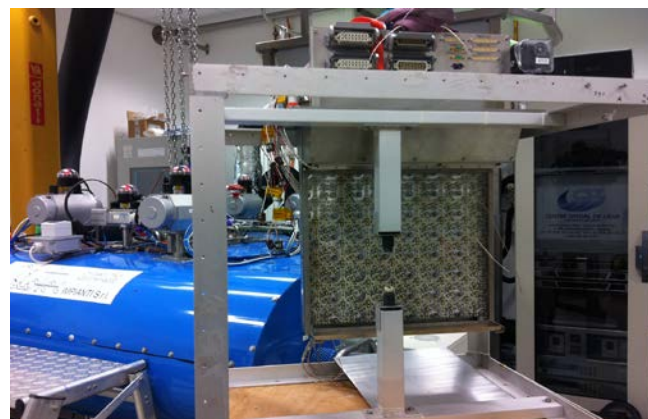


Fig. 3: From left to right: Fast ambient thermal cycling chamber ATC-5 (manufactured by Criotec Impianti, [Italy]), support frame, SCID solar simulator and SCID electrical cabinet (both manufactured by CSL [Belgium]).

All SCID functions and performances, including current forward biasing and loading (i.e. through resistors) of solar cell samples, are monitored and controlled by means of power supplies and digital recorders, governed by computer

programs developed and verified by CSL and Selex-ES (Italy). See Fig. 4.

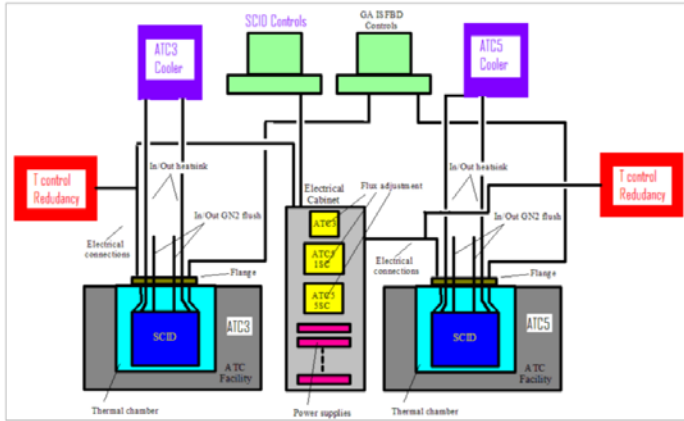


Fig 4. SCIDs functional and electrical diagram.

V. SCID FACILITIES PERFORMANCE VERIFICATION

The SCID facilities performance was verified during the final acceptance test campaign. The SCIDs solar simulator intensity, uniformity and spectral match were verified to be in accordance with the requirements. Calibrated component and full triple junction solar cells were used for this purpose. The results showed initially more energy, than AM0, in the top cell spectral region and therefore the triple junction solar cell was current limited by the middle cell being this under the right AM0 energy for this spectral region. Therefore by decreasing properly the intensity of the white LEDs, the SCIDs simulators provides the right AM0 spectral energy for the top cell. The uniformity mapping was performed by positioning a triple junction solar cell in the different target locations, as indicated in Fig. 5, showing the good correlation with the predicted homogeneity calculated during the design and analysis phase.

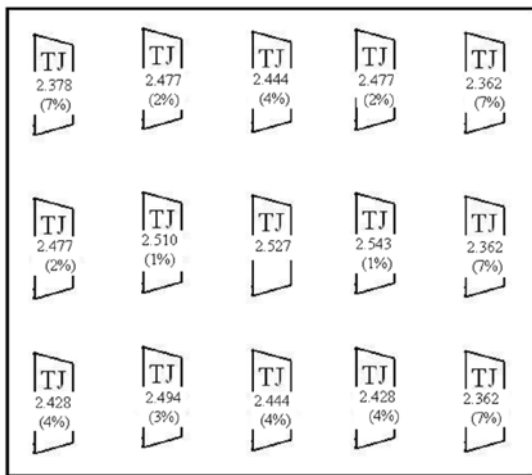


Fig 5. Uniformity mapping with a triple junction solar cell of SCID operating at 5 S.C.

SCID facilities were running together with the fast ambient pressure thermal cycling facilities (ATC-3 and ATC-5) at extreme temperatures for several hundred of cycles. The SCIDs solar simulators were switched on at the end of the cold leg of the cycle and switched off at the end of the hot leg of the cycle, in order to be fully representative of the space environment entering and coming out of eclipse. It was verified that the operational temperature of the halogen lamps and LEDs was within the recommended values specified by the respective manufacturers during the complete cycle duration, see Fig. 6.

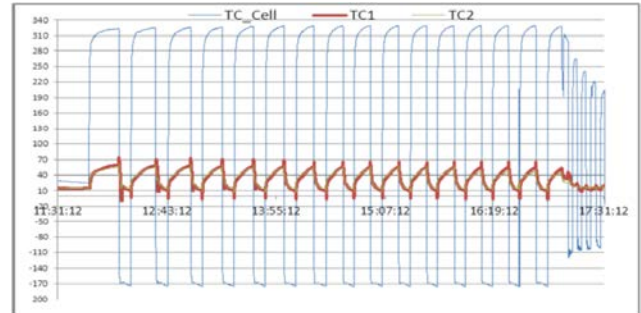


Fig 6. Temperature recording of SCID operating at 5 S.C. between 320°C and -170°C in ATC-5 facility. In red and green the temperatures of the SCIDs lamps and LEDs.

VI. CONCLUSION

SCIDs solar simulators, together with their mechanical and electrical sub-systems were designed, developed, manufactured and successfully verified by CSL, to operate under the extreme thermal conditions of ESTEC ambient pressure thermal cycling facilities.

SCIDs solar simulators allow to perform thermal cycling test campaigns under more representative space environmental test conditions for the complete mission life time on space solar cell device samples or any other samples of other spacecraft subsystems directly exposed to the space environment (e.g. sun sensors, antennas, ... etc).

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