Optimized Space Solar cells for Mars Missions

OptimisM - Executive Summary Report

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1. Introduction

Most space solar cells are designed to provide highest performance values under the AM0 spectrum (as it is prevalent in space) and is optimized in terms of radiation tolerance. More specifically, they must assure a defined performance at the end of their mission, also defined as ‘end of life’ performance. This is mainly correlated to a power output after the expected degradation caused by high energy electron and proton irradiation without perturbation by any atmosphere. For missions of the Mars surface the conditions differ a lot compared to these standard ones and for practical reasons the evaluation of existing space solar cell technologies followed by an adaptation of the most promising one is considered as most appropriate solution for developing a dedicated solar cell for future Mars missions.

In this activity, AZUR SPACE Solar Power GmbH selected and optimized an existing solar cell concept from the existing product portfolio to reach highest performance under pre-defined Martian conditions with still sufficient high radiation tolerance to allow long mission durations. In addition, these solar cells are compatible with flexible solar array concepts which may become a baseline concept for future Mars missions when compact stowage of the PV panels will be a key performance factor and mission driver.

The following three overarching objectives of the project have been defined, whereas all have been achieved successfully:

- At least a +10% higher power output under the pre-defined “Exomars nominal worst case” spectrum at 197 W/m² and at 301 K compared to the performance of a standard 3G30 cell.

- Manufacturing of hardware sample cells inclusive measurements under AM0 as well as covering the given five Martian conditions plus derivation of input parameters for a two-diode solar cell model. Furthermore, temperature coefficients measurements between -150 °C and +50 °C at minimal five points in this range including spectral responsivity and dark-IV measurements.

- Principle compatibility with flexible solar array concepts.

With these objectives met, a significant improved cell technology compared to the state-of-the-art 3G30 architecture for future missions on Mars is found, based on AZUR’s 4G32 cell technology. Furthermore, the relevant two-diode model parameters were derived from measurements under relevant mission temperatures and illumination conditions to allow modeling of almost every mission scenario on mars.

2. Adaptation

Since conditions on Mars vary strongly depending on the landing position, the season and the daily weather conditions, ESA provided five different scenarios with different spectral distributions, different intensities as well as different temperatures.

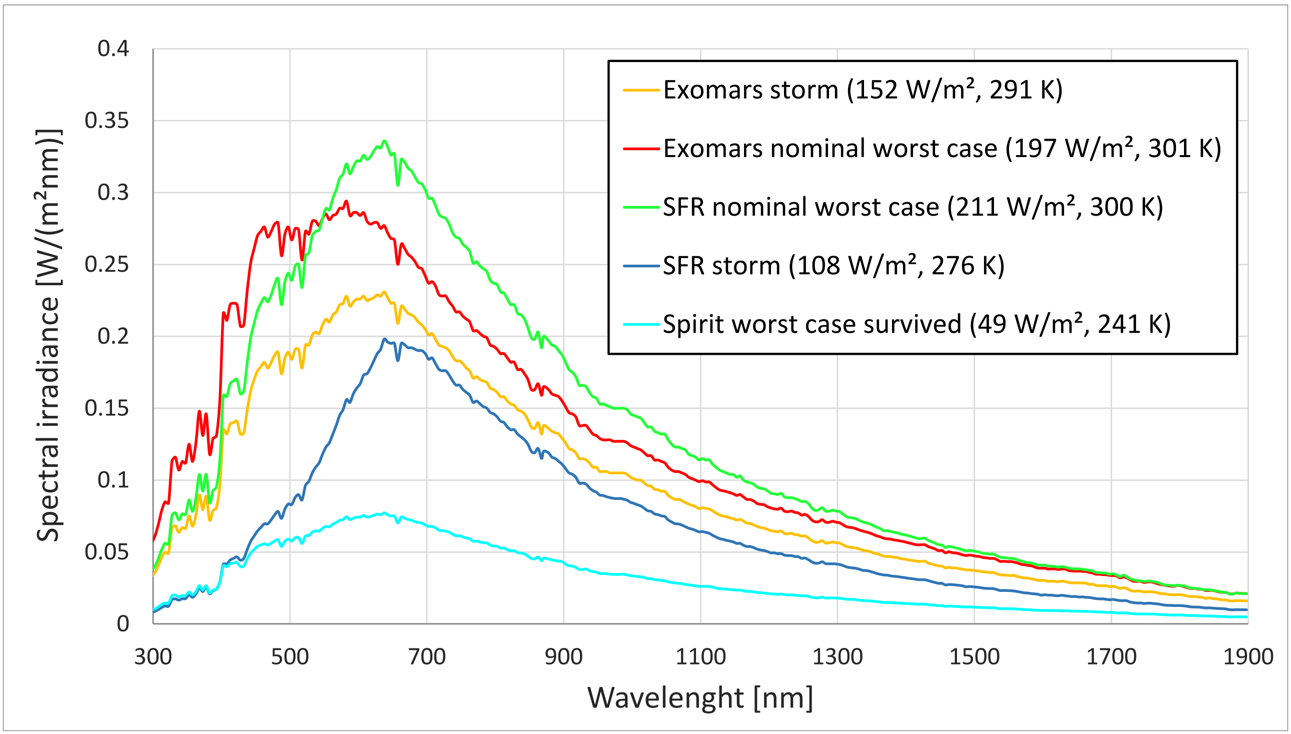


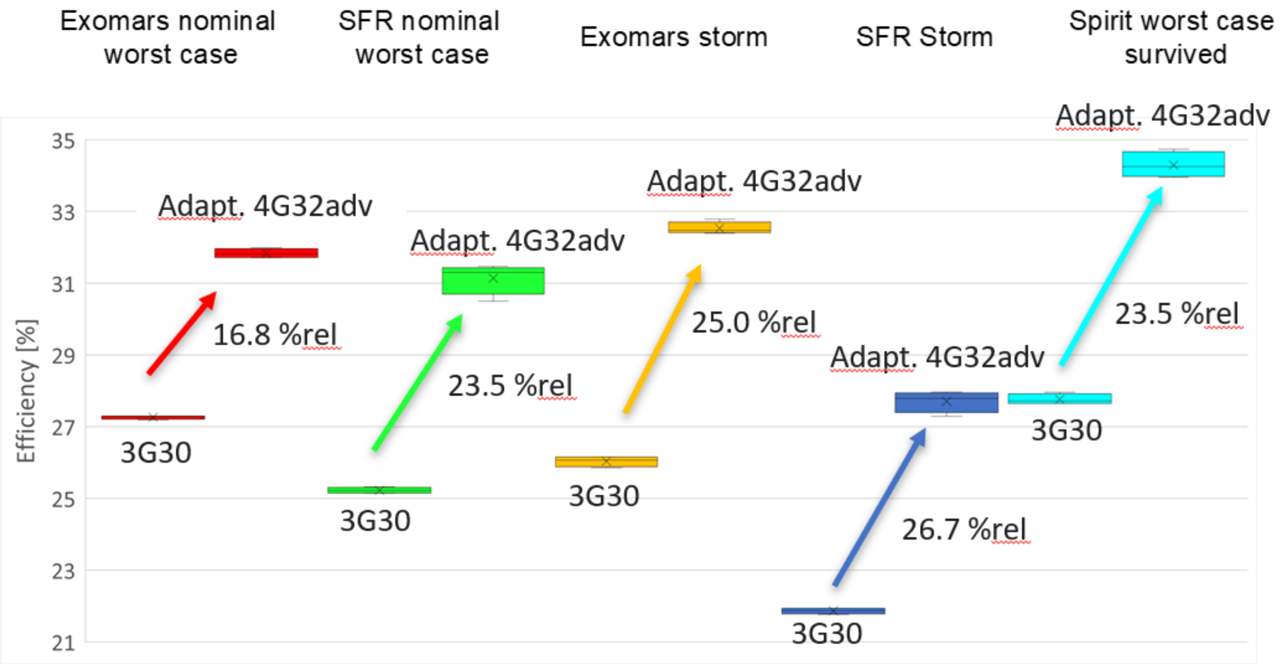
Figure 1: Overview of the different Mars spectra proposed by ESA.

Thirteen epitaxy wafers with the adapted epitaxy structure were manufactured by AZUR SPACE. Together with two reference wafers, all 15 wafers were then processed to 2x2 cm² solar cells. To optimize the grid layout, a new mask with 1100 µm grid finger spacing was designed to adapt the solar cell to the reduced irradiation of the sun's spectra on Mars.

To optimize the epitaxial structure, the absorption wavelengths of J1 and J2 sub-cells were increased by 30 nm each to achieve current matching for the scenario "Exomars nominal worst case". This has been realized by reducing the Al-content of J1 by 3.5 % and of J2 by 7 % (*delta in absolute percentage*). For lower Al-content, equal or better material quality is expected by AZUR SPACE.

Thickness and doping of all active layers are the same as in 4G32-Advanced cell structure. Therefore, the radiation stability of the individual sub cells should be like 4G32-Advanced, apart from the bandgap modification. The radiation hardness of this particular four-junction cell is however lower than this one of 4G23-Adv, because the current-matching for Mars is a begin of life (BOL) design. There is no excess photocurrent in the junctions with stronger current degradation compared to the 4G32-Advanced with respect to AM0. However, as the expected irradiation dose is very low, a potential end of life (EOL) current-matching for Mars missions will not significantly differ from the applied BOL current-matching.

In other words, a low-risk design was chosen for this first efficiency assessment. Further design optimizations are possible in the future but will probably involve thicker cell structures to increase bandgaps and sub-cell voltages. These thicker cell structures would generate risks to be investigated and would also increase cell cost, giving the reason for them to be omitted in this first study.



In the final work package, parameters have been extracted that are needed for a model that allows for the calculation of the solar cell performance under any illumination and temperature conditions on the Martian surface (cell level). For this parameter extraction the temperature dependent absolute spectral response is used as well as the temperature dependent dark currents that can be derived from the dark IV measurements of the component cells. Both, spectral response and dark IV measurements have been performed in the last chapter and are used as basis for this model. The parameters extracted can be used as input for a 2-diode model of AZUR SPACE 4J cells.

Testing of the extracted parameters shows sufficiently low deviation between measured and calculated dark IV curves. Comparisons of light IV curves measured and calculated for the five Martian scenarios show good agreement. Furthermore, the testing of the extracted parameters show that they are valid in the temperature range 241 K to 323 K, only. Extrapolation to outside of this temperature range is not recommended.

3. Summary

The overall goal of the project was to develop a multijunction solar cell that has at least 10 % relative improvement than a standard 3G30 solar cell. The 4G32adv cell was identified as the best base for this improvement. By adapting the cell structure and the grid design, an efficiency of 31.83 % was achieved. Compared to the 3G30 efficiency of 27.26 %, an overall improvement of 16.76 % was archived for the proposed “Exomars nominal worst case” scenario, well exceeding the project target. Several 2x2 cm² cell samples including component solar cells was manufactured and characterized by Fraunhofer ISE. From the temperature dependent spectral responsivity and dark IV measurements, input parameters for a two-diode model were extracted and a simulation model was established. The results of the model were then verified by comparing the simulated data with experimental measurement data of the developed solar cell.

Since the adapted solar cell is mostly based on the qualified 4G32adv solar cell structure, the adapted solar cell can in general be considered like the 4G32 too, ensuring the compatibility with flexible solar arrays at increased specific power.