Metal halide lamps - Simulation of power generating solar arrays for secondary arc investigation

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Abstract

A new method to simulate power generating solar arrays of spacecraft is presented. By combining a multijunction solar array, InGaP-GaAs-Ge, and a metal halide lamp (MHL) secondary arcs were generated. The aim was that the arcs should be comparable to those generated by the currently used methods, which are the solar array simulator (SAS) or a power supply combined with a current regulating diode (CRD) circuit.
The results of the experiment showed a successful generation of secondary arcs, especially of temporary sustained arcs. The arc duration is similar for all three simulation methods. The conclusion therefore is that the MHL method can be used in the same way the SAS or CRD method can be used, as it generates the same results.

1. Introduction

Currently two possibilities are available to simulate the power generating solar array on spacecraft in ground experiments. Those are the solar array simulation method and the so-called current regulating diode method. First these two possibilities will be introduced, followed by the presentation of a new method to simulate the solar arrays on spacecraft. Subsequently a discussion of the gained results, including a comparison of the three methods in terms of the arc duration and the characteristics of the arc waveforms, is done.

2. Solar Array Simulator

The solar array simulator (SAS) is a direct current power supply with the impedance characteristics of a solar array. The inner circuit of the simulator is confidential and therefore no changes to this circuit are possible. The SAS is basically a current source with very low output capacitance of 50nF [5]. To simulate different solar arrays the I-V curve of different arrays under different conditions can be programmed into the simulator. To simulate different internal capacitances of a real solar array, an external capacitance circuit is necessary.

3. Current Regulating Diode Circuit

The current regulating diode (CRD), also often referred to as the current limiting diode or constant current diode, circuit can be attached to any suitable power supply. For the discussed experiments the CRD circuit is combined with the solar array simulator. The internal capacitance of the CRD circuit is around 135pF, one CRD has a capacitance of around 1pF [4]. The CRD function is a limitation or regulation of the current value over a specific voltage range. A detailed CRD circuit description can be found in [2].

4. Simulation Circuit

The circuit in Figure 1 can be split in four parts.

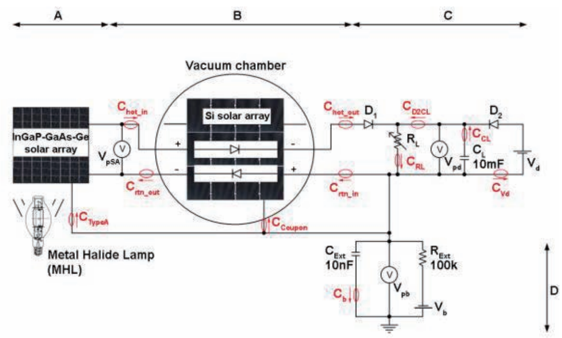

Figure 1 MHL - system circuit

Part A, the left most part, is representing the power generating solar array simulation method. In case of the MHL method this would be the InGaP-GaAs-Ge solar array and the metal halide lamp. In the other cases either the solar array simulator or the SAS and CRD combination. Part B, the middle part of the circuit, is the vacuum chamber representing the space environment to which the solar arrays are exposed and electrostatic discharge (ESD) mechanisms are investigated. The pressure in the chamber was $5x10^{-3}$Pa and the electron temperature was around 0.2eV. The ECR plasma source generated a plasma density of $1x10^{12}m^{-3}$ and the Xenon gas flow rate was 0.4sccm. The chamber size is 1m in diameter and 1.2m in length.

Part C, the right most part, simulates the bus from the solar array to the spacecraft and protection devices of a spacecraft against ESD. Part D, the lower right part, is used to bias the solar arrays to different potentials.

The array inside the vacuum chamber consists of single-junction silicon solar cells. The used coupon contains 12 silicon solar cells. Four cells in a row are connected by interconnectors forming a string. The strings electrical equivalent is a diode due to the p-n-junction nature of the single solar cells which are combined to the string. For the spotlight experiments two strings of the silicon solar array are used. In the following explanation they are referred to as hot-string and return-string. The names are resulting from the direction of the current flowing out of the power generating solar array into the coupon (hot) or out of the coupon back into the power generating array (return). The current probes measuring these currents are designated as $C_{hot\text{-}in}$ and $C_{rtn\text{-}out}$ in part A of the circuit and $C_{hot\text{-}out}$ and $C_{rtn\text{-}in}$ in part C of the circuit. The substrate of the silicon solar array is biased to the output voltage of the power supply determined as V_b in part D of the simulation circuit. This is necessary as in its real environment the solar array substrate would have the same potential as the surrounding plasma. Also the two used strings of the solar array are biased to the same potential, as this would again be the case on a solar array in its real environment in space. The substrate of the solar array is covered with Kapton® tape on the backside to prevent arcing everywhere other than on the solar cells and their interconnectors. Part C of the simulation circuit contains two diodes, D_1 and D_2. D_1 protects the solar array in part B from any occurring arc current. Having the same functionality, D_2 protects the power supply referred to as V_d. Both diodes are legitimate in terms of realistic simulation as both of them exist on a real system in space. The capacitance C_L of part C of the simulation circuit represents the capacitance of the bus between the solar array and the spacecraft. In the ground experiment it also stabilizes the output of the power supply referred to as V_d. The variable resistance R_L allows for variegating the output power of any of the simulation methods of the power generating solar array. The remaining part D of the simulation circuit biases the solar array inside the vacuum chamber as well as the multijunction solar array or the capacitances of the SAS and CRD method to a certain potential.

5. MHL system

The idea for this new method is based on the fact that it is the intention of the solar array simulator and the CRD method to simulate a power generating solar array as realistically as possible. Therefore taking a real solar array and a light source and comparing the results of all three methods seemed very interesting.

The spectrum of the multi-junction solar array, Figure 2, shows it can operate in a range of electromagnetic radiation with wavelengths reaching from 300nm to 1,600nm. A metal halide lamp best fits the electromagnetic radiation spectrum. Its radiated wavelength lies within a range of 400nm to 1,200nm. The graph in Figure 2 does not include the Ge part of the spectrum as it plays a minor role in terms of the solar arrays efficiency and a more sophisticated spectrometer would be necessary to measure this part of the spectrum.

A test done by JAXA showed the multijunction solar array can survive 140°C during 168h [3]. To ensure the temperature does not exceed the allowed maximum value it is controlled with an infrared temperature sensor. For safety issues it was chosen to shadow the solar array in case no measurements were taken. Therefore a shutter is placed in between the MHL and the solar array. The shadowing is done because switching the MHL on and off within a short time frame would reduce the lifetime of the lamp significantly. To allow cooling of the lamp while it's covered, the shutter leaves room to preserve air circulation. The circulation provided by fans generates enough cooling for the illuminated solar array that its surface temperature hardly exceeds 100°C when the distance between the MHL and the solar array is about 25cm. In this temperature region the proper function of the solar array is guaranteed.

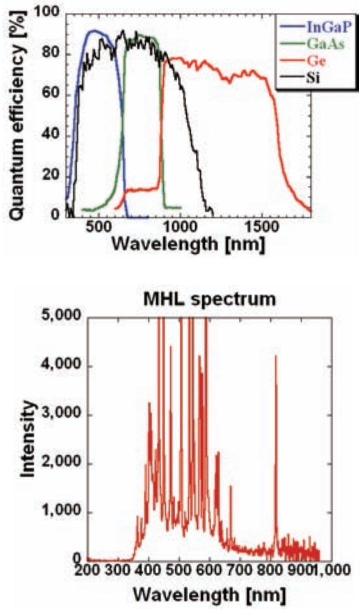

Figure 2 Multijunction solar array spectrum (top), MHL spectrum (bottom)

Taking the IV-curve of the solar array, the output power is adjusted by the variation of the variable resistance value in part B of the simulation circuit and by the amount of light illuminating the solar array. The output power is measured using a differential voltage probe labeled V_{SA}.

To be able to direct the light onto the solar array, a reflector on the backside and two wing reflectors are used (Figure 3). The reflection angles of the two wings can be changed to control the amount of light to which the solar array is exposed to. A top and bottom reflector are not necessary because the light of the metal halide lamp is radiated horizontally, centered on the center illumination point. The color temperature of the metal halide lamp can be controlled with the supply voltage provided through a controller. The color temperature, for MHLs in general, reaches from 2,700K to 20,000K. The color temperature range of the metal halide lamp used for the experiment reaches from 3,900K to

4,800K. During the experiments the color temperature was set to 4,700K. With this color temperature and the mentioned distance to the solar array, an output voltage of 90V and a current of 500mA could be generated. The system includes one metal halide lamp with 3,000W.

6. Metal Halide Lamp

The working principle of a metal halide lamp can be described in four steps. First, the metal atoms move away from the hot arc, which occurs between the two electrodes on the top and bottom of the arc tube and toward to the wall of the arc tube, which has a lower temperature than the arc. The center between the two electrons is what is called the center illumination point and marks where the highest amount of electromagnetic radiation is emitted. On the tube wall the metal atoms combine with the halides and generate a stable molecule. Reaching the hot arc, the molecule breaks and the metal atoms become energized and generate light.

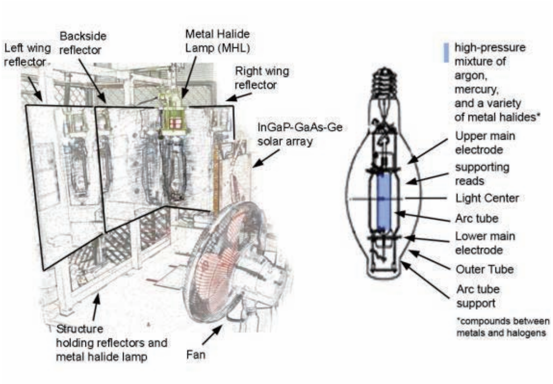

Figure 3 MHL mounting (left); MHL sketch (right)

The halides then move back to the tube wall. In case a metal atom does not combine with a halide it can diffuse through the tube wall. The MHL lifetime ends if the number of diffused metal atoms exceeds a certain limit. In case of the used metal halide lamp the lifetime is stated to be at least 3,600h of operation.

7. Analysis

To analyze the discharges, the solar arrays electric equivalent, the discharge sources and the target point where the discharge occurs are of interest. The solar array simulator and the circuit referred to as the current regulating diode circuit are including capacitances which simulate those of a solar array. These capacitances play a critical role for the discharge waveform and therefore the effects that the discharges have on solar arrays.

The waveforms in Figure 4 are showing temporary sustained arcs. These waveforms are chosen as representative waveforms because the temporary sustained arc is the most interesting type of discharge in terms of potential hazard to a solar array. Of course the sustained arc is the one which definitely destroys the affected strings but this type of discharge is not simulated. One of the aims of the metal halide lamp experiment is to generate temporary sustained arcs and compare them to those generated by the solar array simulator method and the CRD method.

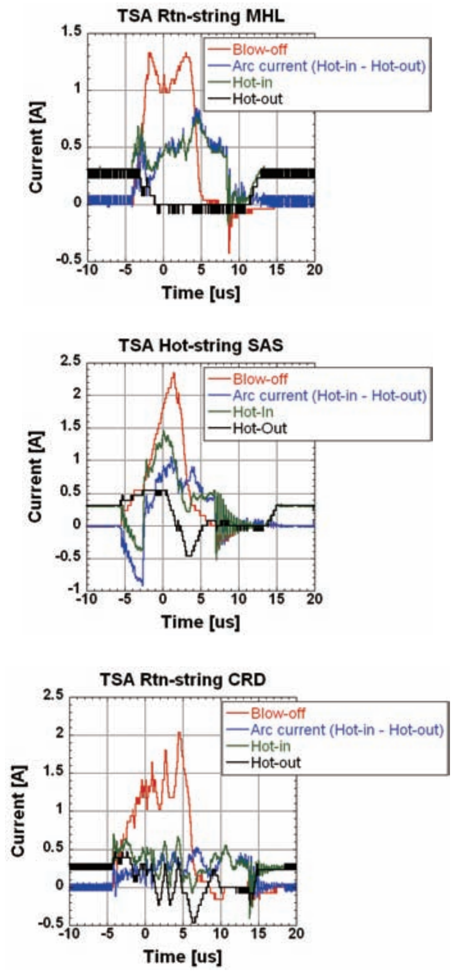

Figure 4 TSA MHL (top), SAS (middle), CRD (bottom)

As can be seen in the waveforms, temporary sustained arcs [1] occurred with all three methods. There is no difference in the arc duration or other arc specifics whether the arc occurs on the hot or the return string. The arc duration is equal or similar for all three methods as shown in Table 1.

	Arc duration [μs]	Standard deviation σ
MHL	4.19	1.733
SAS	4.50	1.553
CRD	4.50	1.412

Table 1 Arc duration comparison

Analyzing the arc path, seen in Figure 5, results in the following observation. First, in this case, the arc occurred on the hot-string of the silicon solar array.

A secondary arc is initiated which transforms into a temporary sustained arc (TSA). A phenomenon which could be observed in the MHL, the solar array simulator and the CRD case is the loss of output current at the end of an arcing event. Figure 5 shows the beginning of the loss at around 8μs and it last until 13μs. The current loss is because of the charging of the internal capacitance of the multijunction solar array, in the case of the MHL method. In the case of the other two methods the internal capacitance of the solar array simulator or the CRD circuit and the external capacitances are consuming the output current. For the current regulating diode method the duration of the output current loss is shorter than the other cases (Figure 4 bottom). This is due to the mode of operation of the CRD which stabilizes the output current over a certain voltage range.

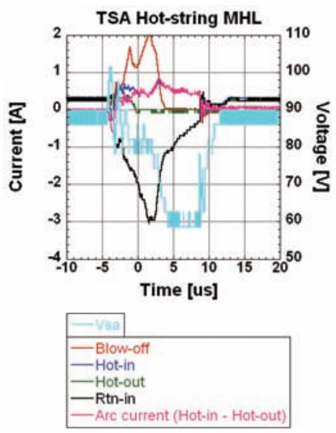

Figure 5 TSA hot-string, MHL method

Considering the multijunction solar array consists of 50 single solar cells which are connected in series, where each cell has a capacity of around 600nF, the whole array has an internal capacitance of 12nF. The output voltage of the solar array is set to 90V and drops to around 60V during an arcing event. The charge of the output current loss is around 900pC which means that a capacitance with a value of around 30pF is discharged.

8. Summary

The conclusion of the MHL experiment is that the arcs are similar to those generated by the solar array simulator and the CRD method. The MHL method has no major disadvantages as it requires no special safety precautions and the overall effort which was necessary to set the system up is not considerably higher than for the SAS or CRD method. The MHL method therefore can be called a third method to simulate power generating solar arrays in ground experiments, without any essential advantages or disadvantages.

References

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