Measurement of ESD threshold voltage of coverglass (CMG100AR)

Nguyen Duc Minh, Arifur R. Khan, Kazuhiro Toyoda, and Mengu Cho.

Abstract — **Coverglass (CMG100AR) is widely used to protect the solar cell from harsh space environment. Due to surface charging, it acts as a platform where electrostatic discharge (ESD) can occur. In order to know the ESD threshold, coverglass is exposed to electron beam, measured the temporal surface potential rise until the discharge. ESD current waveform and discharge images are also recorded. ESD threshold voltage is statistically measured by Weibull distribution.**

Index Terms — **Solar cell coverglass, current density, vacuum chamber, space environment, surface potential distribution, electron beam, Atomic Oxygen.**

I. INTRODUCTION

The surface damage and performance degradation of high voltage solar arrays caused by arcing or electrostatic discharge (ESD) has been studied widely [1],[2],[3],[4]. This arcing occurs at the triple junction when coated solar cells of various power ratings are exposed to elements of the space environment, such as: high energy vacuum UV radiation, Atomic Oxygen (AO), plasma, temperature extremes, etc. This ESD is the result from potential differences between the surface of a spacecraft and solar cell. Sometimes, ESD at high threshold voltage can damage the solar cell's efficiency and can even cause cell-to-cell short-circuit through the string gap. This can lead to stop supplying power to the necessary component and can even cause the satellite failure [5],[6],[7],[8].

Currently, solar cells are coated with coverglass to provide protection from the harsh radiation environment, such as: UV, collisional impacts from space debris and micrometeoroids, ionizing radiation, and the presence of Atomic Oxygen, etc. To improve on performance in light transmission, the coverglass is coated with an antireflection agent, such as MgF2 which can reduce the net sunlight reflected from the solar cell. However, the performance of the coverglass may be changed with time as it is continuously exposed to elements of the space environment, such as: Atomic Oxygen, UV, electron/proton ionizing irradiation, etc. To know the effect of Atomic Oxygen on solar cell coverglass, this experiment measure the threshold voltage of ESD on coverglass produced by Qioptiq Ltd. In this paper, a characterization of ESD threshold voltage on virgin has been attempted by using electron beam to expose the coverglass sample and measure the temporal surface potential rise until the discharge.

II. EXPERIMENTAL SETUP

1.I. Sample preparation.

Cerium doped CMG100-AR coverglass produced by Qioptiq Ltd. has been selected. The specification of CMG100-AR coverglasses is listed in Table 1. It is widely used in the most major satellite programs for both civilian and military applications.

Table 1. Specification of Sample

Sample	CMG100-AR solar cell coverglass
Manufacture	Qioptiq Space Technology, UK
Front surface	110 nm thickMgF_2 coating
Substrate	100 µm thick CMG
Doping	Cerium doped
Substrate density	2.554 g/cm^3
Min.	83.5%, 350 - 400 nm, 95%, 400 – 450 nm
Transmission	97.0%, 450- 900 nm, 96.5%, 900 – 1800 nm

This experiment used 4 CMG100-AR coverglass samples to measure the threshold voltage of ESD and the schematic of the sample configuration is shown in the Figure 1. All samples were connect with SPEC555 wires by using dolite (silver glue) on the back side and put above one acrylic plate. The current density was also measured by using a 20mm x 20 mm copper plate which was fixed adjacent to the samples.

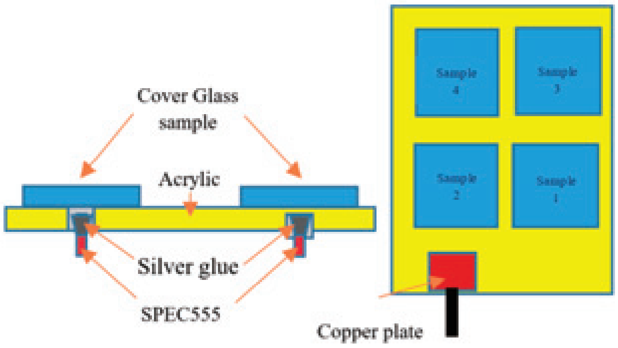

Figure 1. Schematic of sample arrangement on substrate. Left: Front view, Right: Top view.

1.II. Vacuum chamber and measurement circuit

Four samples were placed inside the GEO vacuum chamber directly under the electron beam irradiation path. A thin Aluminum foil was attached under the electron beam gun to reduce the electron beam current density. The measurement of copper plate to make sure that the current density of electron beam around 7.5 $\mu A/m^2$ incident on the sample. One vacuum motor driven shutter was also placed below the electron gun and Aluminum foil in order to stop irradiation immediately prior to the surface potential scan by a non-contact potentiometer probe (TREK). A camera was set outside the vacuum chamber and focused on the samples in order to take the discharge image run by a Quick Look LabVIEW program. By using the base image and discharge image were taken by this camera, the location of the discharge can be known. To measure the current due to discharge on each sample, current probes from Cp-2 to Cp-5 (shown in Fig.2) were installed outside the chamber and Cp-1 was used to measure the blow-off current pass to the external capacitor with a capacitance of 300pF. During the experiment the samples was biased to -4kV by a high voltage DC source. A high voltage probe (attenuation, 1000:1) was used to monitor the voltage drop of the samples due to discharge. All the current probe signals and high voltage probe signal were fed to a 8-channel Oscilloscope. The pressure inside the chamber was set up around 3 x 10^{-4} Pa and electron beam energy was fixed approximately 5keV. All data of current probes and high voltage probe was recorded by a LabVIEW program. Schematic arrangement of the samples placed in the vacuum chamber with electrical circuitry is shown in Figure2. 2D surface potential distributions before and immediately after the ESD were measured by a non-contact potentiometer (TREK) controlled by a LabVIEW program. From the beginning, time was recorded.

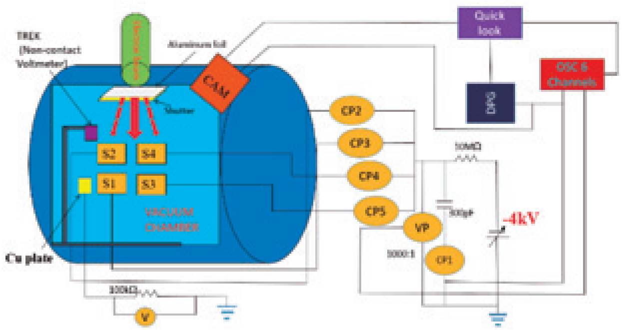

Figure 2. Schematic of samples placed on the vacuum chamber and related circuit is shown.

III. EXPERIMENTAL RESULTS

Surface potential of the sample was measured by a non-contact voltammeter before and after using electron beam to irradiate the sample. Figure 3 shows the 2D surface potential distribution after the sample has been biased (left) and charged by electron beam irradiation (right). In Figure 3, the left picture shows the potential distribution after the sample has been biased by a -4kV, whereas the right picture shows the increase of surface potential after 60 seconds electron beam irradiation. Figure 4 also shows the surface potential before and after the discharge occur. All samples have been highlighted by a black square outline in Figure 3, 4.

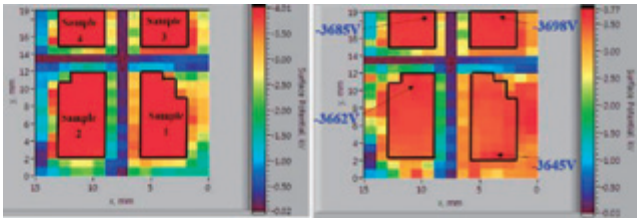

Figure 3. 2D surface potential distribution after biasing to -4kV and before the electron beam exposure (left). The right side shows the potential distribution after 60 seconds using electron beam irradiation.

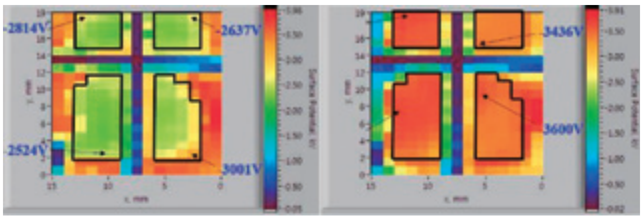

Figure 4. 2D surface potential distribution before and after discharge occur. Left: Before discharge, Right: After discharge.

Current from Cp-1 acted as a trigger to the camera to take the discharge image on the sample. In Figure 5, the left figure illustrates the base picture of all samples inside vacuum chamber and the right panel shows the locations of ESD which is taken by camera triggered by discharge.

When a discharge on any sample occurred, the surface potential of the sample was reduced to nearly biased voltage and current passing through four SPEC555 wires to the external

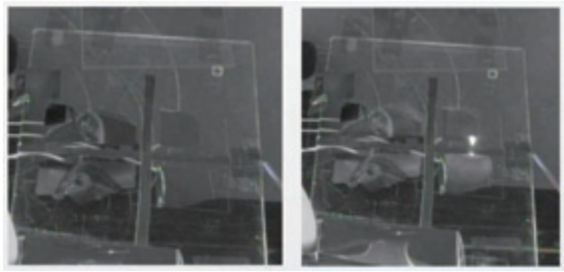

Figure 5. Base picture and ESD picture taken by camera.

capacitor would be measured by four current probes (Cp-2 to Cp-5). In figure 6, the left image shows the current waveforms of fours probes (Cp-2 to Cp-5) recorded simultaneously. The highest waveform (blue line) indicates the ESD occurred on the sample 1. The right panel shows the ESD image captured by the camera. Similarly, when a discharge occurred on the sample 4 (black line), the discharge current waveform and voltage waveform (from high voltage probe) were detected and recorded, shown in Figure 7.

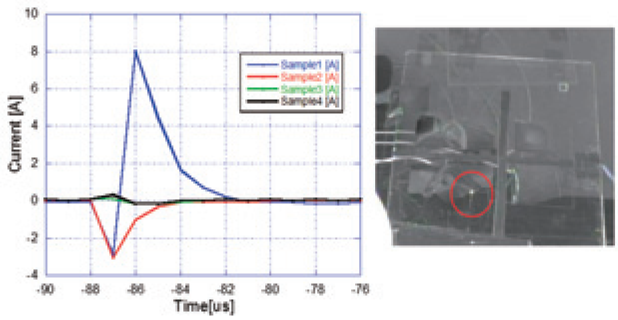

Figure 6. Discharge current waveforms (left) due to discharge on the thermal exposed sample. Corresponding ESD image captured by camera, inside red circle, is also shown (Right).

Many discharges were detected on samples while the biased sample surface was exposed to the electron beam. Under electron beam exposure, the surface potential would rise exponentially. As the threshold voltage was approached and exceeded, a discharge would occur. Immediately following discharge, the

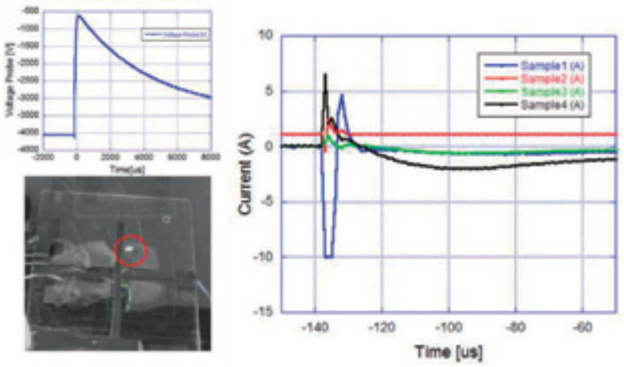

Figure 7. Discharge current waveforms and voltage waveform due to discharge on the thermal exposed sample. Corresponding ESD image captured by camera, inside red circle, is also shown.

surface potential was measured by a non-contact voltammeter. However, it was very difficult to measure the threshold voltage just before the discharge occurred. So that, a large number of pre-discharge surface potential measurements were recorded on samples and a charging profile in the time domain was determined and fitted exponentially by taking the negative value of surface potential. Figure 8 shows the charging profile of discharge sample (blue dots) and the exponential fit to the data (red line). Once the charging profile was determined, the surface potential just before discharge occurred could be determined (inside red circle in Figure 8) based on the recorded time and threshold voltage could be calculated.

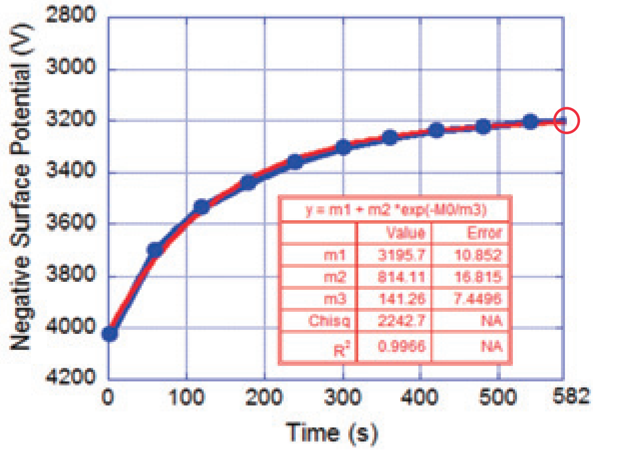

Figure 8. Charging profile coverglass while -4kV biased sample was exposed to electron beam. Blue circles are the surface potential measured by TREK before the discharge occurred. Red line is the exponential fitted curve. Fitting parameters are shown on the table.

On all the samples, a total of 35 ESD were recorded. Measured ESD threshold voltages on the virgin samples are shown in Figure 9. The minimum threshold voltages found for the virgin coverglass samples were 612V. In order to find the threshold value statistically, both Normal distribution and Weibull distribution methods were applied. Figure 10 shows curves for the Weibull and Normal cumulative distribution function. From these curves, ESD threshold voltage is determined at the point where the distribution function equals 0.5. These results are shown in Table 2.

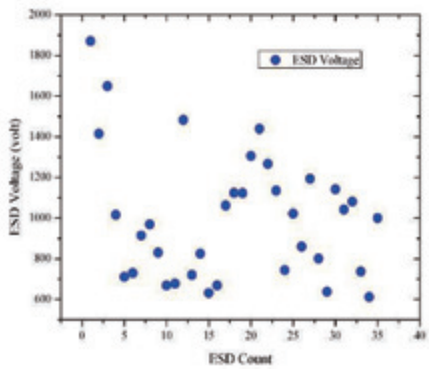

Figure 9. Threshold voltage of ESD on virgin samples while under electron beam irradiation.

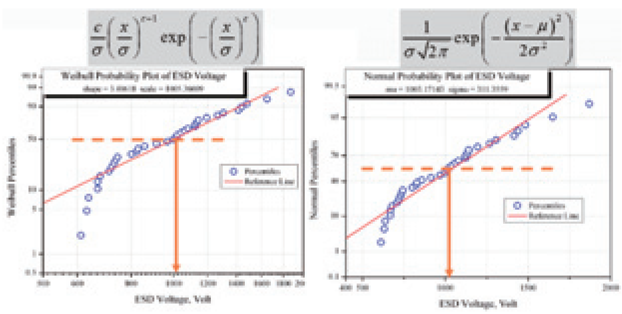

Figure 10. Cumulative Weibull (left) and Normal (right) distribution of the threshold voltage of ESD measured on virgin samples.

Table 2. Threshold voltage of ESD on the virgin samples measured by Weibull and Normal distribution.

Distribution	ESD threshold at 50 % Virgin sample
Weibull	1.005 kV
Normal	1.003 kV

IV. CONCLUSION AND FUTURE TASKS

CMG100-AR coverglass, which produced by Qioptiq Ltd, have been irradiated under electron beam inside a ground vacuum chamber to measure the threshold voltage of electrostatic discharge (ESD) after were biased to negative voltage. A lot of number of ESD on virgin samples occurred and were observed. ESD current waveforms and images also were recorded simultaneously. Around 35 ESD data were obtained on the virgin samples and both Normal and Weibull distribution functions were used to measure the ESD threshold voltage. It has been found that the ESD threshold voltage of virgin sample is around 1kV. In future work, more virgin and Atomic Oxygen exposed samples will be considered to investigate the ESD threshold.

V. REFERENCES

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