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Lifetime of Channel Electron Multiplier Detectors dedicated to Plasma Instruments for Solar Orbiter and JUICE space missions

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ABSTRACT

Both Solar Orbiter and Jupiter Icy moon Explorer (JUICE) are long-life ESA missions, which should work in extremely difficult space environment. A very high thermal load up to 13 Solar constants will affect Solar Orbiter, and JUICE will experience a high penetration radiation influence in the Jupiter magnetosphere. The plasma packages of these missions, dedicated mostly for detection of low energy (between 1eV and 50 kev) ions and electrons shall accept a very high dynamic range of the incident charged particle flow. All these circumstances motivate us to use the Channel Electron Multiplier (CEM) as detectors in both missions. CEMs are a classical low energy charged particle and X-ray detectors that have been used fore many early space missions. Later, they were forced out by Micro-Channel Plates (MCP), which allow to provide an image of the particle distribution. But for such challenge missions as Solar Orbiter and JUICE we have to come back to CEMs because they 1) less sensible to the penetrating radiation 2) have much wide dynamical range, 3) have much longer lifetime than MCPs. The detector lifetime is, actually, the maximum particles number accumulated by detector until its efficiency becomes too low. And this detector feature is critical for Solar Orbiter and JUICE missions.

To check the lifetime of CEMs, for different thermal conditions also, we have made a dedicated experimental setup. We irradiated several CEM samples by a strong electron flux, continuously measuring the CEM gain and keeping 80°C on the sample. The final total number of events, detected by each CEM was equivalent to 20 years of the continuous operation in space. The experiment has shown the excellent lifetime properties of the CEMs, chosen for the missions

.

Keywords: Detectors, Electron multipliers, CEM

1. INTRODUCTION

The conventional photomultiplier tubes, invented in the 1930, employed a photocathode to convert the detected photon to a photoelectron, and a discrete dynode electron multiplier to amplify the charge of the single initial photoelectron to the level that can be recorded by commercial electron circuits. But such detector is not optimal for the space application because it cannot be exposed to the air, thus it cannot be used in an "open configuration" and cannot be used for vacuum UV measurements. The concept of a continuous-dynode electron multiplier has been proposed by Farnsword [1], but in the real working device has been created on 1960s, with the development of high surface resistance glass [2],[4]. From this epoch up to our days the single Channel Electron Multiplier (CEM) is used for Ultraviolet Photoemission Spectroscopy, X-ray Photoemission Spectroscopy, and also for charged particles (electrons and ions) spectrometry. Despite strong competition from the multichannel plates (MCP), we still use CEMs for space applications especially for the plasma instrument where we need a very long lifetime and very high count rate per channel. Note that plasma spectrometers usually do not need a very high spatial resolution of the detector.

1.1 CEM basics

The production of high-resistance surface on lead glasses led to the independent development of the continuous channel electron multiplier in Soviet Union by Oschepkov [3] and in USA by Goodrich [2]. The mode-of-operation of CEM is shown in Figure 1.

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The multiplier is operating under vacuum with a high voltage established along the channel. An energetic photon (> 5eV) or charged particle striking the wall of the channel releases an electron that is accelerated along the channel axis, until it strikes the wall with sufficient energy to release again secondary electrons. This process is repeated many times, and, finally, produces an output pulse of charge containing up to 10^8 electrons.

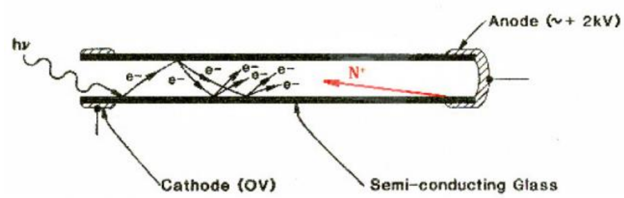

Figure 1. Schematics of the CEM

The number of electrons (or the detector gain) producing by a CEM increases with increasing of the high voltage applied to the channel, but saturates and does not grow anymore from some voltage level. This is because the electron cloud charge stops new secondary electrons acceleration and, as the result, stops electrons multiplication. The ion produced by electron impact ionization of the residual gas can cause a strong noise generation. The new ion is accelerated back to the CEM entrance, create a new secondary electron there and triggers new avalanche of electron multiplication. This “ion feedback” can be prevented by curving the channel (see subsection 1.2).

1.2 CEMs for Solar Orbiter plasma packages

The ESA mission Solar Orbiter contains a Solar Wind Analyzer (SWA) package as an important part of the *in situ* measurements of the solar wind plasma flow. One of the instruments of SWA plasma package is the ion spectrometer PAS which has to provide up to 20 3D ion distribution functions per second. From the measurement point of view, to get 3D ion distribution function, we have to record the ion flux spectrum in the <energy, elevation, azimuth> space. The electrostatic ion optics provides the energy and elevation binning, and the ion detector provides the resolution in the azimuthal dimension. The ion detector will resolve 11 bins of 6° each. The main problem is that each bin of such detector shall record up to 10^7 events per second to fulfill the required dynamic range of the instrument which has to operate at the Earth orbit as well as at 0.28au distance to Sun. We found that only ceramic CEMs produced by “Dr. Sjuts Optotechnik GmbH” [5] can fulfill such heavy requirements. Figure 2 shows the PAS ceramic detector schematics and the CEMs installed in the PAS prototype. There are eleven CEMs inside PAS covering 66° of the azimuthal range and providing 6° of azimuthal resolution.

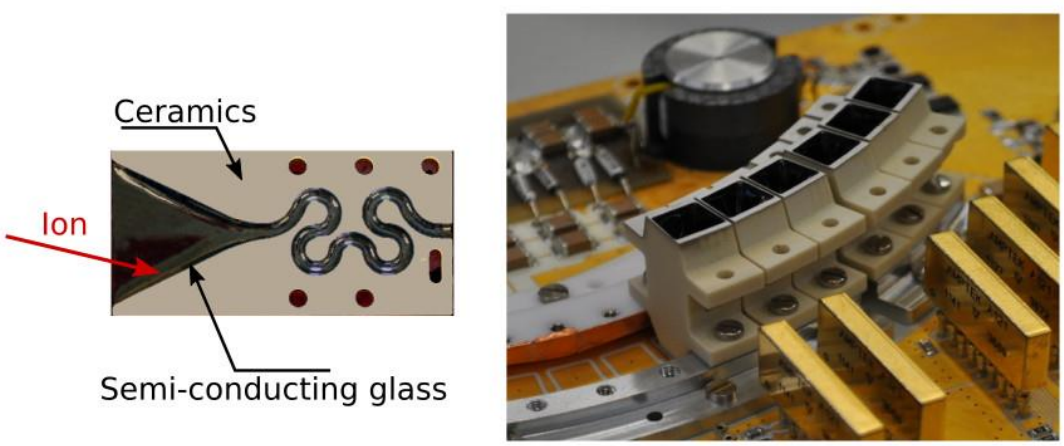

Figure 2. Left: Ceramic CEM design. Right: CEM array installed in PAS prototype.

Such ceramic CEMs can be easily adapted to fit any configuration, integrated to an array and/or modified to get another entrance geometry.

1.3 Requirements for CEM Lifetime

Solar Orbiter nominal mission duration is about 7 years. Taking into account possible several extensions of the mission, we have to ensure at least 15 years of PAS lifetime. It is well known [6],[7] that CEMs as well as MCPs degrade with the accumulated event count. I.e. the CEM gain is going down as a function of the total output charge. We explain such gain degradation by a physical mechanism in which the surface ionization process results in removal of the electron source through reaction with a finite resident population of poisoning species. One of the advantage of CEMs is that their lifetime is long, much longer than the lifetime of MCPs. Estimations show that to survive during 15 years, the CEM installed in PAS has to get 5 C of output charge without significant degradation of the characteristic gain. Since the maximal output charge very depends on the CEM type and CEM manufacturer, the specific CEM type and even specific CEM badge shall be checked for the lifetime.

Every 6 months Solar Orbiter will approach to Sun down to 0.28au. During several weeks of closest approach the CEMs temperature will reach 70°C. These circumstances make us to formulate another important requirement: “The lifetime of CEM shall be verified for the temperature up to 80°C.

2. LIFETIME EXPEREMENT SETUP AND PROCEDURE

1.4 Experiment setup

Experiment diagram is shown in Figure 3. We tested simultaneously three CEMs. Three independent HV sources with HV precise current measurement individually polarized CEMs. Three CEMs anodes were separated from the CEMs and integrated to the PCB containing also the HV circuits and filters. The CEM entrance is under zero voltage and the CEM exit is under the bias voltage. The anode is shifted for 100V relatively to the CEM exit to ensure the electrons collection.

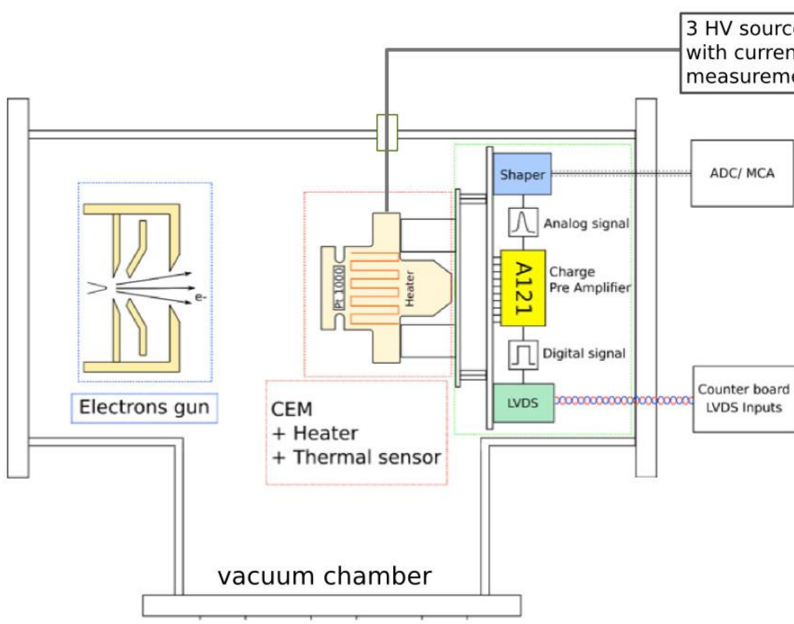

Figure 3. Experiment diagram.

One electron gun, centered above the CEM setup, radiated the CEMs by electrons of 1keV energy. The electron flux was almost uniform over the CEMs entrance. We could regulate the electron flux with high precision varying the filament current.

The CEM front-end electronics consists of Amptek A121 fast charge-sensitive amplifier. We use both digital and analog outputs of the amplifier. The digital outputs of three amplifiers are connected to the counter (3 channels in parallel) via LVDS interface and the analog outputs are connected to three multichannel analyzers (MCA).

We heated the CEMs assembly by two heaters glued to the external CEMs. We used a standard temperature regulator to keep the CEM assembly under a constant temperature during the experiment.

A computer-controlled system based on the VME bus rack and corresponding modules controlled the CEM HV bias, the gun filament current, and read the CEM count rates, CEM output pulse high distributions and CEM strip currents. A central computer collected all this information, calculated runtime the CEM gains and controlled the experiment without any operator intervention.

1.5 Experiment procedure

The current in the CEM HV circuit consists of two parts: the strip current (the current that flows through the channel walls) and the current of electrons leaving the CEM and collected by the anode (anode current). The strip current depends on the CEM temperature, which depends on the total current. But if the free electrons current is much less than the strip current (< 10%), we can consider the strip current as independent on the electron current.

The philosophy of the experiment is as follows: we load the CEM by a relatively high incident electron flux and periodically we measure the CEM gain, If the gain is out of some predefined narrow corridor, we change the CEM HV bias to put the gain into the corridor again. And we continue this process until the CEM bias is too high.

Thus we have two modes of experiment activity:

- The gain measurement. During this phase we reduce the incident electron flux to get the CEM anode current almost zero (unreadable). Then we use the feedback from the counter to tune the incident electron beam and to get the CEM count rate about 5×10^3 s-1. Then we perform the CEM pulse hight distribution accumulation and calculate the gain. If the cane is out of predefined corridor, we tune the CEM HV bias.
- Charge accumulation. We use the feedback from the anode current measurement to tune the electron beam flux and to set the anode current about 10% of the strip current.

The total accumulated charge is the integral of the anode current.

3. EXPERIMENT RESULTS

Figure 4 shows the first test results performed under the ambient temperature.

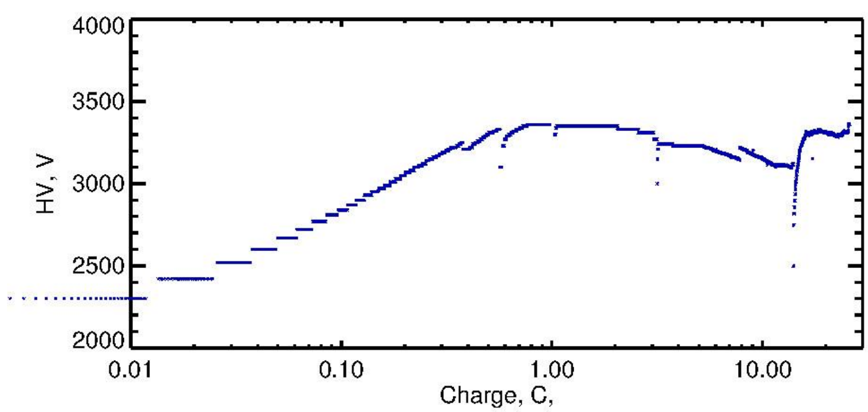

Figure 4. CEM HV as a function of the total accumulated charge while the CEM gain is constant. Taken for the room temperature.

When total accumulated charge is less then 0.6C the HV increases quickly that is a fast CEM channel degradation. This is a signature of CEM "scrubbing" when the electron flow inside the channel removes absorbed contamination species like water etc. Usually such contamination created the additional secondary electron yield, and the specified gain may be reached with much less HV bias than the working bias. Then, when the CEM is "scrubbed", the gain (and corresponding HV bias) is stabilized. We even slightly decreased the HV bias to keep the gain constant. The negative bursts of the HV bias show the cases when we, for some reasons, were opening the vacuum chamber. The CEM absorbed water at those moments and new scrubbing returned the HV bias to the previous level. The total accumulated charge in this experiment was 20C and the HV bias always was inside the reasonable limits.

The first experiment with rather high CEM temperature is shown in Figure 5. Here we see the same type of profile of HV bias as a function of the total charge. The CEM scrubbing has been completed at the charge of 0.4C. We completed this experiment at 5.9C of total charge that corresponds to the double load of the nominal Solar Orbiter mission.

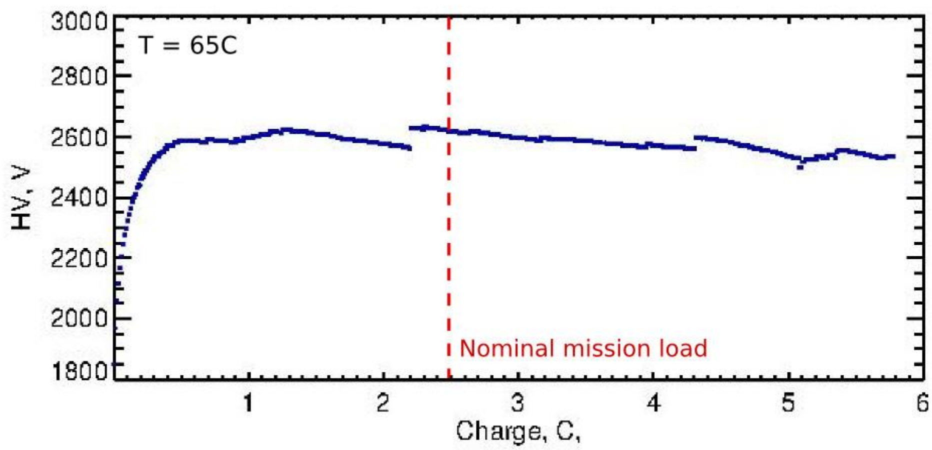

Figure 5. The same as Figure 4, but for temperature 65°C. The horizontal scale is linear.

All other experiments we performed up to 4C to save time. Figure 6 shows the summary plot for four temperatures from 65 to 80°C.

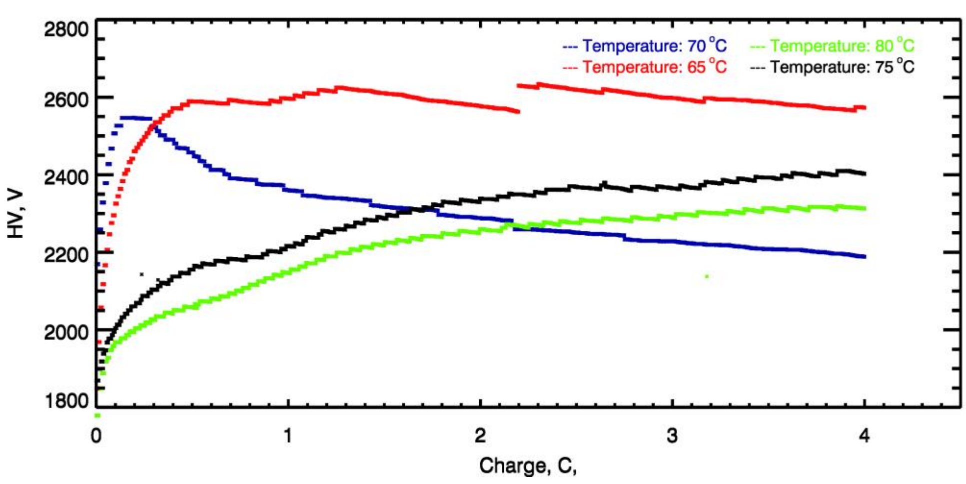

Figure 6. The same as Figure 5, but for four different temperatures.

We can see that for temperatures equal or less than 70°C the HV bias profile is stabilized or even decreasing. For the temperature above 70°C we see a slowly increasing HV profile that means a continuous degradation of the channel. But we cannot be sure if it is a real temperature effect of just a sample-to-sample variability.

4. SUMMARY

1. Below 70°C the ceramic CEMs by "Dr. Sjuts Optotechnik" show stable gain at least up to 5C of total accumulated charge
2. There is some evidence that above 70°C the CEM is degrading slowly in the acceptable range. Even in this case the CEMs can keep up to 4C load and may be used for Solar Orbiter mission.

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