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Differential Gain Stability of a MicroChannel Plate Detector dedicated to a Neutral Particle Instrument (JENI) of the JUICE space mission

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ABSTRACT

The Jupiter Icy moon Explorer (JUICE) is a long-life ESA mission to be working in extremely harsh space environment. The energetic neutral atoms imager (JENI), designed as a Time-of-Flight (TOF) spectrometer, contains microchannel plate (MCP) detectors to register start and stop secondary electrons produced by incident neutrals atoms. Due to rather severe mass and power constraints this spectrometer uses a single MCP assembly to detect both Start and Stop electrons, to define their detection time and then calculate an incident particle velocity. Thus one MCP is divided in several sectors. One of them is dedicated to detect Start electrons and another sector is detecting Stop electrons. Since the load of the Start sector can be higher than the load of the Stop sector by a factor of 10, it is important to know how does the MCP sectoral gain (Differential Gain) change during the MCP lifetime. Since the JUICE mission is a long-time mission it is important to be sure the MCP gain changes evenly along the active surface. To characterize the MCP overall gain uniformity we have combined the gain uniformity measurement and differential gain stability measurement into a single experiment of the MCP aging. A differential gain stability test has been performed on a representative MCP assembly using a uniform UV light source. The differential UV exposure has been achieved using an attenuation mask provided ~10% exposure of a majority of the MCP surface and full exposure of a small area. Differential gain versus the MCP bias voltage has been characterized every 0.5 C/cm^2 of the charge extracted out of the MCP. We have shown the spatial gain variations and the differential degradation of the MCP sectors are acceptable for JENI experiment.

Keywords: MCP, JUICE mission, ENA imager, JENI, neutral particle instrument, differential gain

1. INTRODUCTION

1.1 Introduction to Microchannel plate technology

Before 1960s the only detector for the vacuum UV, soft X-rays and low energy charged particles was a conventional photomultiplier tube. This detector employed a discrete dynode electron multiplier to amplify the charge of a single initial photoelectron (or any other particle to detect) to the level that can be recorded by commercial electron circuits. In 1960s, with the development of high surface resistance glass[1], a continuous-dynode single Channel Electron Multiplier has been invented. Such detector is widely used for laboratory and space experiments up to now, but it lacks imaging properties. Since there are only two constants critically important for a single channel electron multiplier: 1) length to diameter ratio, 2) high voltage applied for the channel, there is a theoretical possibility to make a number of very small channels (10 μm in diameter for instance) and bond them to produce a detector with an image recording capability. This type of detector ("Microchannel plate", MCP) was firstly made in Bendix Research Laboratories. The MCPs made by fiber optics technologies, such as we apply to the present time, has been created in BURLE TECHNOLOGIES[2].

The MCP schematics[3] is shown in Figure 1. A single one channel multiplier is operating under vacuum with a high voltage established along the channel. An energetic photon (> 5eV) or charged/neutral 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 10^5 electrons. Such gain is enough for night-vision devices, but not enough for scientific imagers that have to give a recordable response on a single particle event. In order to obtain higher gain without ion feedback (which generates dark count noise in the straight channel) a "chevron stack" of two MCPs is applied[3,4] (Figure 1, right). The gain of such MCP stack is about 10^7 electrons. The channel pitch is about 20 μm that gives us the maximal image resolution and an operating voltage is about 2000 V.

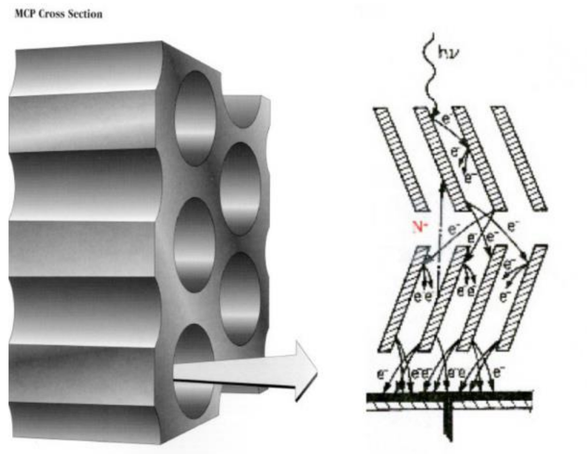

Figure 1. Schematic showing mode-of-operation of the MCP[3]

1.2 JUICE mission and neutral particles observations

Magnetosphere of Jupiter is apart from the Sun the strongest source of charged particles in the Solar system. The interaction of these particles with the exospheres of the Jovian moons forms one of the most complex plasma laboratories encountered by human space flight. For this reason the Plasma Environment Package (PEP) forms a crucial experiment of the Jupiter Icy Moon Explorer (JUICE). PEP performs the science investigations relevant to Jupiter magnetosphere, moon-magnetosphere interactions, and moon neutral environments. The energized neutral atoms (ENA) imaging, providing by JENI experiment, allows to perform remote diagnostics of the plasma processes during interaction of an icy moon with the Jovian magnetosphere.

1.3 JENI instrument system design and MCP degradation requirements

JENI is an imaging energized neutral atom spectrometer providing a spatial image of a source on the neutral particles and their energy and mass analysis. It is a NASA-sponsored APL instrument. A very simplified operation scheme of JENI is shown in Figure 2.

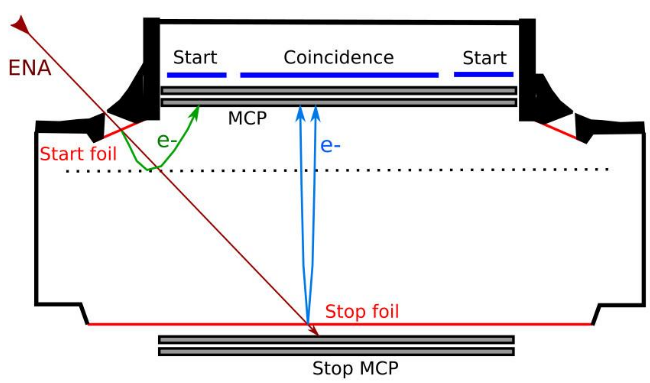

Figure 2. Simplified ENA detection scheme of the JENI instrument

An incident neutral atom (ENA) is passing a fine aperture and then is passing through a very thin carbon foil. Secondary electrons generated on the inner side of the foil are moving towards an upper MCP and being recorded by a Start anode. The ENA continues movement towards a Stop foil and generates there secondary electrons which also move towards the upper MCP. These secondary electrons are recorded by a "Coincidence" anode. The time between the Start and Stop events gives us the particle velocity. The "Stop" MCP under the Stop foil gives the neutral particle angular image.

To reduce the mass and consumption of the instrument, the "Start" and "Coincidence" electrons are multiplied and being recorded by one large MCP with one high voltage power supply. The MCP channels degrade with the accumulated number of events recorded by the MCP[5]. The channel gain is decreasing as a function of a total accumulated charge. The problem is that the flux of Start electrons might be 20 to 50 times greater than the flux of coincidence electrons. Thus the "Start" part of the upper MCP can degrade quickly and lose the efficiency faster than the "Coincidence" part. We have to avoid this situation in flight. The requirement is to keep the gain uniformity of the MCP within 20% at the end of the experiment lifetime.

1.4 Experiment goals

To characterize the MCP overall gain uniformity we have combined the gain uniformity measurement and differential gain stability measurement into a single experiment of the MCP aging. A differential gain stability test is to be performed on a representative MCP chevron pair using a uniform UV light source to flood the MCP surface. The differential UV exposure is to be achieved using a mask provided full exposure of two small areas located aside the central part of the MCP and attenuated beam exposure of the rest majority of the MCP surface. Differential gain vs. bias voltage is to be characterized after every 0.5 C/cm^2 of a total charge is extracted until a total extracted out of the MCP charge reaches 5 C/cm^2.

2. EXPERIMENTAL SETUP

2.1 General description of the setup

An experimental setup is shown in Figure 3. The setup consists of the following parts: a vacuum chamber, a uniform UV source located on the top part of the chamber (see Figure 4), an intermediate diaphragm (collimator base) separating the chamber volume in two compartments, upper and bottom one, a collimator tube located in the upper compartment, a box with the MCP setup inside located on a XY sliding table in the bottom compartment. The UV source, the XY sliding stage and the MCP setup can be controlled remotely and automatically. The collimator base does have two openings. A rectangle opening allows the MCP assembly to be fully illuminated by UV provided the MCP setup is located below the rectangle aperture. A small pin-hole of 0.8mm in diameter is located in the other part of the collimator base. A collimator tube is installed right above the pin-hole and below the UV source in order to reject reflected UV photons and secondary electrons. The collimator tube together with the pin-hole forms a needle UV beam.

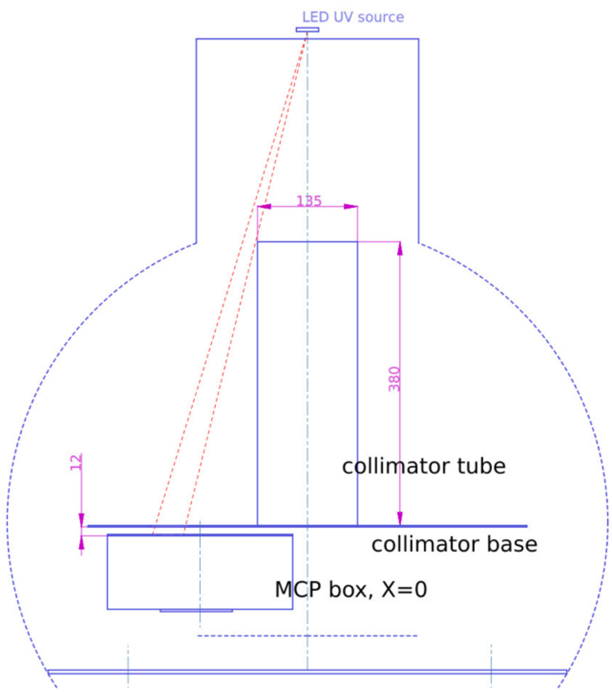

Figure 3. The experimental setup allows two configurations. In the Scrubbing and Charge accumulation configuration the MCP setup is exposed to UV emission. In the Differential Gain characterization configuration the MCP box is located below the collimator tube. The needle UV beam is used to measure the MCP gain step-by-step in every point of the MCP surface. The small plate shown under the MCP box is a XY stage interface.

The experiment can be performed in two configurations: Scrubbing and Charge accumulation configuration and Differential Gain characterization configuration. In the Scrubbing and Charge accumulation configuration the MCP box is moved right under the rectangle opening in the collimator base to be fully exposed to UV emission. In the Differential Gain characterization configuration the MCP box is moved away from the rectangle opening towards the pin-hole. Following step-wise movement of the MCP box allows to scan the MCP surface with a pin-shaped UV beam and measure the MCP gain in each point. The MCP box movement is provided by means of a XY sliding stage. The small plate shown in Figure 3 under the MCP box is a XY stage interface.

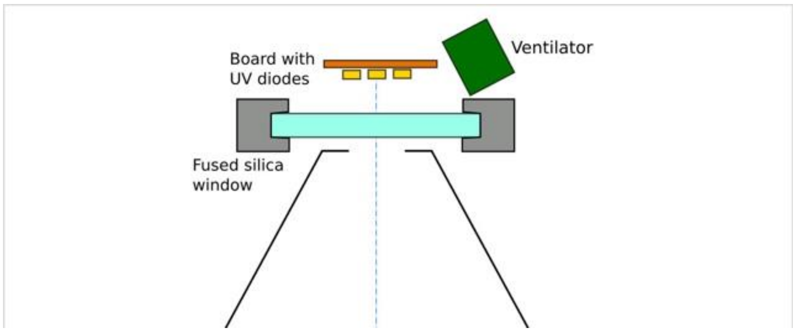

Figure 4. UV LED source installation. The UV source is located outside the vacuum chamber to allow better cooling of the powerful UV LEDs by means of a ventilator. UV light emitted by the UV LEDs passes through a fused silica window which is transparent to UV emission.

A snapshot of the experimental setup is shown in Figure 5. The vacuum chamber is capable of creating and keeping ultra-high vacuum in the range of vacuum pressure of ~2x10^{-7} mbar. The UV source is a high luminosity UV LEDs source located outside of the vacuum chamber behind a UV grade (Fused Silica) window on the top of a drift tube. The UV LEDs are powered by a computer controlled current source. The intermediate diaphragm is an aluminum plate separating the upper and bottom parts of the vacuum chamber. A rectangle opening, visible on the photo, allows the MCP assembly to be fully illuminated by UV light. A needle UV beam is created by a pin-hole in the collimator base and the collimator tube installed above the pin-hole. Below the collimator base the MCP box is located. The space between the collimator base and the MCP box is about 15 mm to allow free MCP box movements along the XY axes. The collimator base is fixed to the base plate of the vacuum chamber.

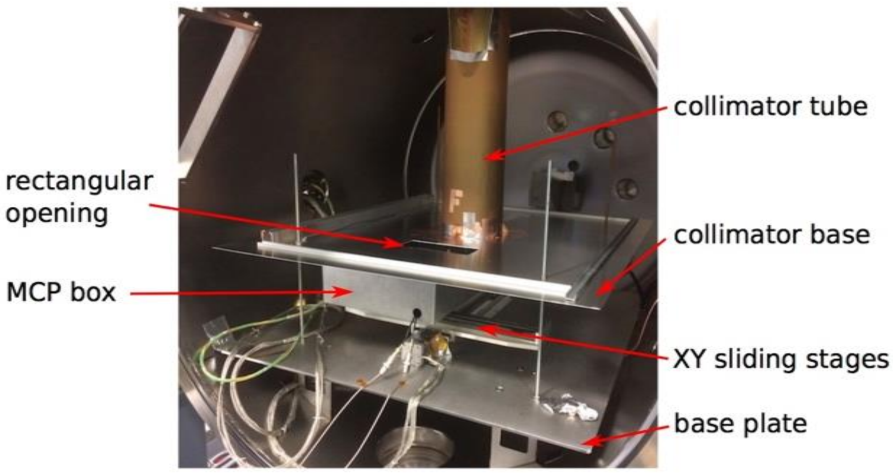

Figure 5. A view on the experimental setup.

2.2 Description of the MCP setup

The MCP setup is shown in Figure 6. The MCP setup consists of a MCP assembly, located inside a closed aluminum box. The top cover encloses the box to protect the MCP detector against reflected UV photons and secondary electrons. There are three rectangle apertures in the cover located as shown in Figures 7, 8 which allow illumination of certain areas of the MCP surface keeping the rest of the MCP surface shadowed. A big middle aperture confines a Coincidence sector of the MCP. This sector will be named as a “STOP sector” in the following text for clarity. Smaller apertures located on both sides of the middle aperture confine START sectors of the MCP. An attenuation mask is mounted above the STOP sector of the cover. The mask is shown in Figure 7. It is an aluminum plate with three openings corresponding to the openings in the top cover of the MCP box. The mask consists of two meshes, the inner and the outer one. Each mesh does have a transparency of ~20% each. Both meshes provide a total transparency of about 10%. So the attenuation mask provides UV attenuation for the STOP sector by a factor of 10 approximately. Two openings in the MCP box cover, corresponding to the START sectors, are opened to allow illumination of certain MCP areas without any attenuation.

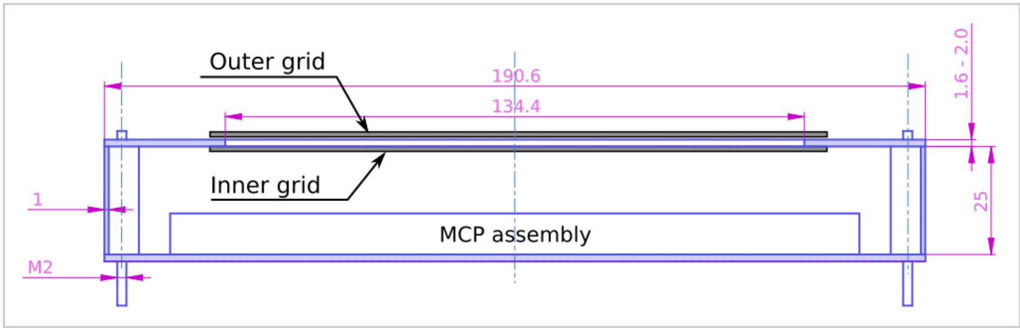

Figure 6. The vertical cut of the MCP box setup.

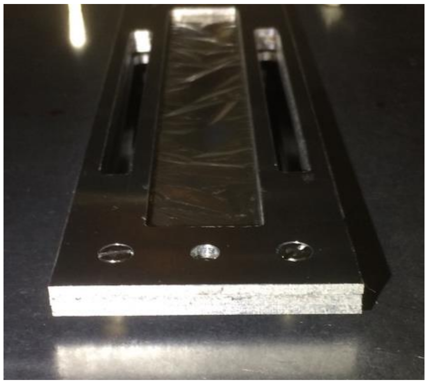

Figure 7. The attenuation mask assembly.

A view from top on the aperture cover of the MCP box is shown in Figure 8. The dark grey central aperture corresponding to the STOP sector is closed by meshes. The light grey apertures corresponding to the START sectors are completely opened for UV light.

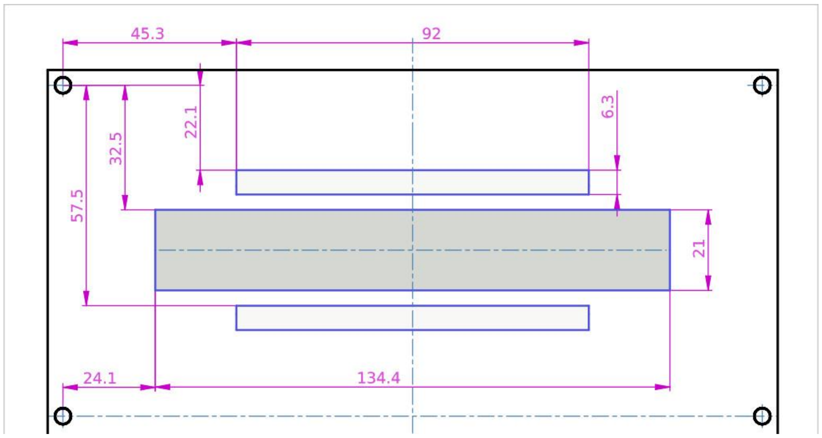

Figure 8. Aperture cover of the MCP box. The dark grey central aperture (STOP sector) is closed by the double mesh. Two light grey apertures (START sectors) are completely opened for UV light.

3. EXPERIMENT PROCEDURE

The philosophy of the experiment is as follows: the MCP is being loaded by a relatively high incident UV flux and we measure periodically the MCP current keeping the MCP bias constant. If the MCP current is getting out of some predefined narrow current range, the UV source intensity is being adjusted to allow the MCP current be back within the predefined range. And this process is being continued until the total extracted from the MCP charge reaches 5 C/cm^2. Every time the total charge extracted out of the MCP increases on 0.5 C/cm^2 the MCP spatial gain variations are being measured.

During the charge accumulation the MCP total current is being kept below the value of 1.1 times MCP strip current. The MCP total current consists of a strip current (the current flowing through the MCP channels walls) and an anode current (the current of electrons leaving the MCP and being collected by the MCP anode). The MCP strip current depends on the MCP resistance and temperature, which in turn depends on the MCP total current. The anode current depends mostly on the MCP load. If the anode current is much lower than the MCP strip current (< 10%), the MCP strip current and the anode current can be considered as independent on each other.

Thus we have two modes of experiment activity:

- The charge accumulation (Scrubbing and Charge accumulation configuration). During this phase the MCP bias is kept constant. The MCP box is moved to the rectangle opening. The incident UV flux is being changed from zero to high enough intensity to set the MCP from a pulse counting mode to a current mode. Then we use the feedback from the MCP anode current measurement to tune the UV flux in order to set the MCP anode current about and less than 10% of the MCP strip current. The total accumulated extracted charge is an integral value of the MCP anode current.
- The gain measurement (Differential Gain characterization configuration). During this phase the MCP HV bias is kept constant. The MCP box is moved to the needle UV beam region. The incident UV flux is set to a predefined intensity to provide the MCP count rate of about 10^3 c/s. Since the STOP sector of the MCP setup provides an attenuation of the UV flux the latter is being increased when the needle UV beam illuminates the STOP sector and is being decreased when the needle UV beam illuminates any of the START sectors of the MCP setup in order to maintain the MCP count rate of ~10^3 c/s. Then we perform the MCP pulse height distribution accumulation and the MCP gain calculation in each point of MCP surface with XY steps of 1 mm.

4. EXPERIMENT RESULTS

4.1 Scrubbing results and initial uniformity

Initially the experimental setup has been assembled without the attenuation mask to allow UV light to illuminate evenly all the MCP sectors during the MCP “UV scrubbing” activity. After assembly the experimental setup was set to the Scrubbing and Charge accumulation configuration and was irradiated by an intense UV flux over a certain period of time to perform the MCP “scrubbing” (with no mask installed). During this period of time the total charge extracted from the MCP reached approximately 0.03 C/cm^2. Then the MCP box has been set to the Differential Gain characterization configuration to perform the MCP gain measurements. The gain distribution over the MCP surface is shown in Figure 9. Left picture shows the measurements performed over the START sectors. Two yellowish rectangles are clearly visible. These are the areas corresponding to the START sectors named “anode1 (left side)” and “anode1 (right side)” for clarity. The reddish area outside the START sectors is a noise counting caused by UV photons reflected from the MCP box cover and it shall be disregarded. The vertical rectangular boxes (black lines) enclose the areas used for gain profile calculations. The right picture in Figure 9 shows the measurements performed over the STOP sector. The orange rectangle is clearly visible. This is the area corresponding to the STOP sector named “anode2 (center)”. The reddish area outside the STOP sector is a noise counting created by UV photons reflected from the MCP box cover and it shall be disregarded. The vertical rectangular box (black line) encloses the area used for gain profile calculation.

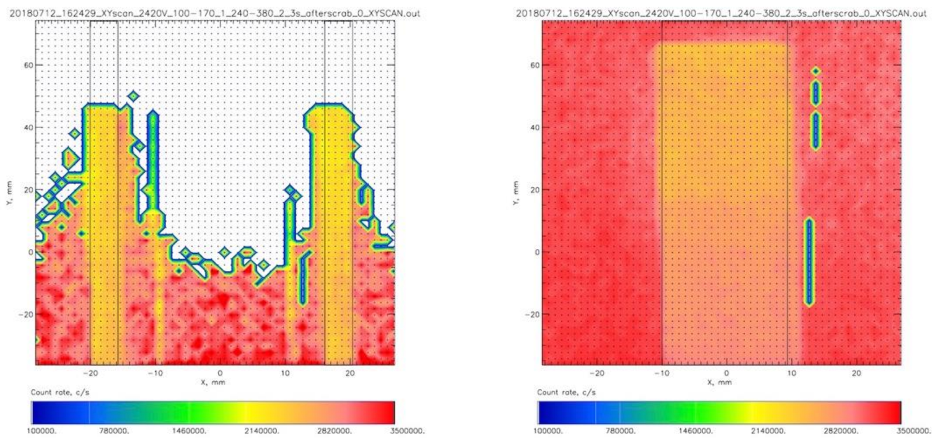

Figure 9. Gain distribution measured over the START sectors (left picture) and over the STOP sector (right picture). The START sectors consist of two parts "anode1 (left side)" and "anode1 (right side)". The STOP sector comprises one part "anode2 (center)". Vertical rectangles define the integration bands used to calculate the gain profiles.

Figure 10 shows the gain profiles of the START sectors (black line - "anode1 (left side)", blue line - "anode1 (right side)") and of the STOP sector (red line - "anode2 (center)"). The gain profiles are integrated over the vertical bands (rectangles) shown in Figure 9. Spatial variations along the sectors are very low. There is a small initial difference between the gain values of the START and STOP sectors. It is due to some difference between the START/STOP front-end electronics channels and will be taken into account while further data processing.

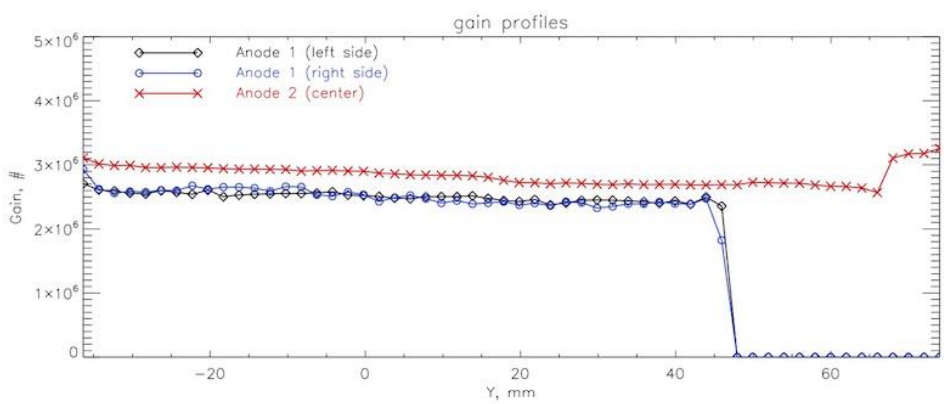

Figure 10. Gain profiles shown for the START sectors: black line - "anode1 (left side)", blue line - "anode1 (right side)" and for the STOP sector: red line - "anode2 (center)". The gain profiles are integrated over the vertical rectangles shown in the gain distribution pictures.

4.2 The differential degradation results

After the MCP "UV scrubbing" activity the attenuation mask was installed. Then the UV source intensity settings were defined for all the START and STOP sectors of the MCP setup to provide a count rate of ~10^3 c/s in each sector. After assembly the experimental setup was set to the Scrubbing and Charge accumulation configuration and was irradiated by an intense UV flux over a certain period of time to perform the differential MCP "aging" (with mask installed). During this period of time the total charge extracted from the MCP reached approximately 0.5 C/cm^2. Then the MCP box has been set to the Differential Gain characterization configuration to perform the MCP gain measurements across the MCP surface. The differential degradation tests are on-going at the moment. The cycle "differential aging – gain measurements" will be repeated until a total charge extracted out of the MCP reaches 5 C/cm^2. The results of the experiment will be reported on the ICSO 2018 conference.

5. SUMMARY

A differential gain stability test is being performed on a representative MCP assembly. The overall gain uniformity measurement and differential gain stability measurement are combined into a single experiment of the MCP aging. The experiment is performed using a uniform UV light source to irradiate one sector of the MCP surface (STOP sector) such that it sees five times lower flux than the rest of the surface (START sectors). The differential UV exposure has been achieved using an attenuation mask with ~10% exposure for the majority of the MCP surface and full exposure for a small area. Differential gain versus the MCP bias voltage is being characterized every 0.5 C/cm^2 of the total charge extracted out of the MCP. Spatial variations along the sectors are very low. An initial small difference between the gain of the START and STOP sectors is causes by some differences between the START/STOP front-end electronics and will be taken into account while further measurements and data processing. The differential degradation tests are on-going. The results of the experiment will be reported on the ICSO 2018 conference.

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