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Resistance and Gain of the Microchannel Plate (MCP) detector as a function of temperature

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ABSTRACT

The microchannel plate (MCP) has been used for decades as a photon, electron and atoms detector in most of the space instruments dedicated for X-rays, energetic neutral atoms, and charged particle imaging. The deep-space missions, as near-future ESA Jupiter Icy moon Explorer (JUICE) mission, expect very low temperature conditions on the destination orbit. Since instruments are usually calibrated on the ground under the "room" temperature, it is very important to know the variation of the detectors properties with temperature. The resistance and the gain of the MCP detectors, dedicated for the JENI (PEP package) instrument onboard of JUICE, were measured as a function of temperature at INTRASPEC TECHNOLOGIES, Toulouse, France for the temperature range -50 to +50 °C and at the CALIPSO-3 facility of the Institut de Recherche en Astrophysique et Planétologie (IRAP), Toulouse, France for the temperature range -25 to +25 °C using samples from PHOTONIS France and PHOTONIS USA. It is also important to know how the resistance of the MCP detector behaves with temperature either to properly size the high-voltage source or, conversely, to choose a technology according to the size of the MCP detector and the maximum current that the high-voltage source can supply. Since the environment of Jupiter is very severe, the instruments will operate in the presence of high-energy particles that will induce background noise on the MCP detectors due to the shielding of the instruments against radiation. Therefore, the background noise in the Jovian environment represents a crucial issue for the MCP detectors whose gain can be degraded prematurely if too much charge is extracted from them due to the induced particles. Ours measurements show that the resistance of the MCP detector increases when the temperature decreases and is influenced by its self-heating, whereas the gain behavior depends on the technology of the MCPs. This is an important result which can be used to optimize the gain performance and the lifetime of the MCP detector. These experimental tests were funded by the French Space Agency CNES.

Keywords: MCP, self-heating effect, resistance, gain, lifetime.

1. INTRODUCTION

Since their first development in the 1960s[1, 2], microchannel plate (MCP) detectors have been used in many applications such as nuclear physics and space astrophysics where they represent an effective means for detecting particles with energies ranging from UV to X-rays and atoms including the heaviest through the use of MCPs at cryogenic temperatures[3]. Over the past four decades, MCPs have been the subject of several studies that have focused on their lifetime[4, 5] and their detection efficiency against radiation[6, 7] or depending on parameters such as the applied voltage, the bias angle, the length-to-diameter L/D ratio, the electrode penetration depth[8], the type of particle[9, 10, 11] or the energy range[12]. However, the limited number of studies available in the literature on the behavior of MCPs with temperature contrasts with the number of applications in which MCPs undergo temperature gradients that can be significant. This is often the case in space applications such as the near-future ESA Jupiter Icy moon Explorer (JUICE) mission, where very low temperature conditions are expected around Jupiter or the ESA Bepi-Colombo mission, to be launched in mid-October 2018 and where, high temperature conditions are expected around Mercury. Since instruments are usually calibrated on the ground under the "room" temperature, it is essential to know the variation of the MCP detector properties with temperature. Pearson et al.[13] were first to estimate the variation of the resistance of the MCP detector with temperature in the range 290-305 K. Subsequently, P. Roth and G. W. Fraser [14] measured the resistance of MCPs over the range 4-278 K in order to optimize their count rate and most recently, A. S. Tremsin et al.[15] performed this measurement over the temperature range -17 to +48 °C and found that the resistance of the MCPs varies exponentially with the temperature. On the other hand, the gain of the MCP detectors is usually given in the existing literature as a parameter that depends only on the L/D ratio[16]. However, by measuring the modal gain of two MCPs of different sizes and characteristics over the temperature range +40 to +160 °C, Slater and Timothy[17] showed a variation of -0.1% / °C with temperature which could result, according to them, from the presence of an axial temperature gradient that creates a non-uniform electric field throughout the MCPs channels. The result of the measurements we present here show that the gain of the MCP detector can vary with temperature depending on its technology. These measurements that we performed at INTRASPEC TECHNOLOGIES in Toulouse, France for the temperature range -50 to +50 °C and at IRAP in Toulouse, France for the temperature range -25 to +25 °C, also show the influence of the self-heating effect on the resistance value of the MCP detector.

2. METHODOLOGY

To measure the resistance and the gain of our MCP detectors we used two different setups and facilities. The MCP resistance measurement was performed at INTRASPEC TECHNOLOGIES facility which consists of a vacuum chamber with a vacuum capacity <5e-7 mbar and inside which a thermal exchanger unit and a PID-controlled Peltier cells module are installed, a chiller whose cooling capacity is 0.3kW at -75 °C and temperature range -75/+60 °C, a 0-20 kV power supply, a picoammeter and eight thermocouples allow to monitor the temperature at different points inside the vacuum chamber. The gain measurement was performed at IRAP's CALIPSO-3 facility which consists of a vacuum chamber with a vacuum capacity <1e-7 mbar, a customized cooling flange in aluminum, a chiller whose capacity is 1 kw at -40 °C and temperature range -40 °C/+80 °C, an electron gun, five 0-5kV power supplies, a 8-channel MCA and a 16-channel DAC converters, a 16-channel counter and three thermocouples to monitor the temperature inside the vacuum chamber. The principle of each measurement is described in the following sub-sections.

2.1 Resistance measurement

The resistance measurement was performed using unscrubbed MCPs from Photonis France in chevron configuration and with small and large plates to assess the influence of the self-heating effect on their resistance. The MCP chevrons were taken from two different batches. Their characteristics are given in table 1 and the test setup is shown on figure 1 below. The MCPs were operated under a vacuum <1e-6 mbar and with a bias voltage of 2kV. The resistance of each MCP chevron was recorded from +50 °C to -50 °C every ΔT=10 °C and 600s after the set temperature was reached by the sensor placed on TOP of the MCP chevron.

Table 1. Characteristics of the MCPs used for performing the resistance measurement.

Batch #	Thickness L (mm)	Pore size D (µm)	Bias angle (degrees)	Dimension (mm²)	Resistance (MΩ)
1	1.5	25	12	18x18	1000
	"	"	"	58x90	52
2	"	"	"	18x18	300
	"	"	"	48x140	14

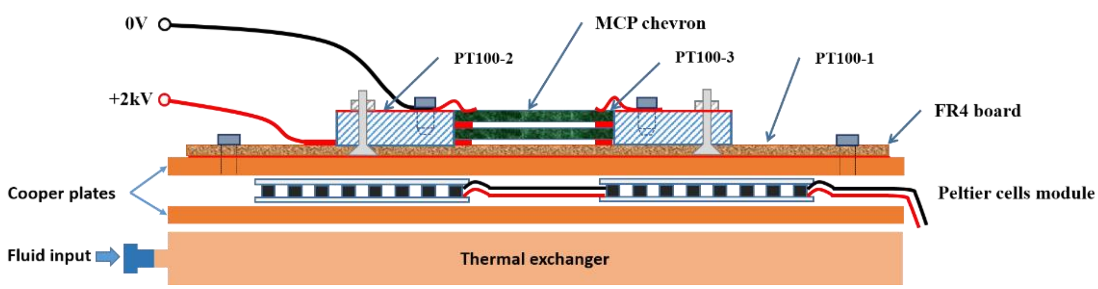


Figure 1. Setup used for measuring the resistance of the MCP chevrons.

2.2 Gain measurement

The gain measurement was performed using MCP samples from PHOTONIS France and from PHOTONIS USA which share the same L, D and bias angle parameters in chevron configuration. Each MCP chevron was taken from different batches dedicated for the JENI (PEP package) instrument onboard of JUICE and was scrubbed, i.e. exposed to an intense electron beam, to extract an accumulated charge of 30 mC/cm² prior to measuring their gain through a statistical approach to take into account a slight drift of the MCP bias with temperature whose maximum value is ± 0.5 % over the entire temperature range. The procedure that follows from this statistical approach is described in figure 2 below.

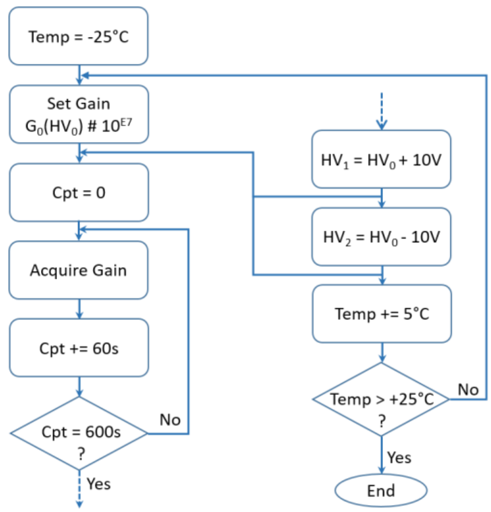


Figure 2. Procedure implemented in order to acquire the gain of the MCP chevrons.

The resistance of the MCP chevrons at ambient temperature (+20 °C) and the test conditions are indicated in table 2 below.

Table 2. Resistance at +20 °C and test conditions of the MCP chevrons used for performing the gain measurement.

Sample #	Manufacturer	Resistance (MΩ)	MCP bias (V)	Open area (mm²)	Count rate (s^{-1})
1	PHOTONIS USA	136	2030	12x12	5000
2	"	151	2160	"	7000
3	PHOTONIS France	1000	2280	"	7000
4	"	190	2050	"	7000

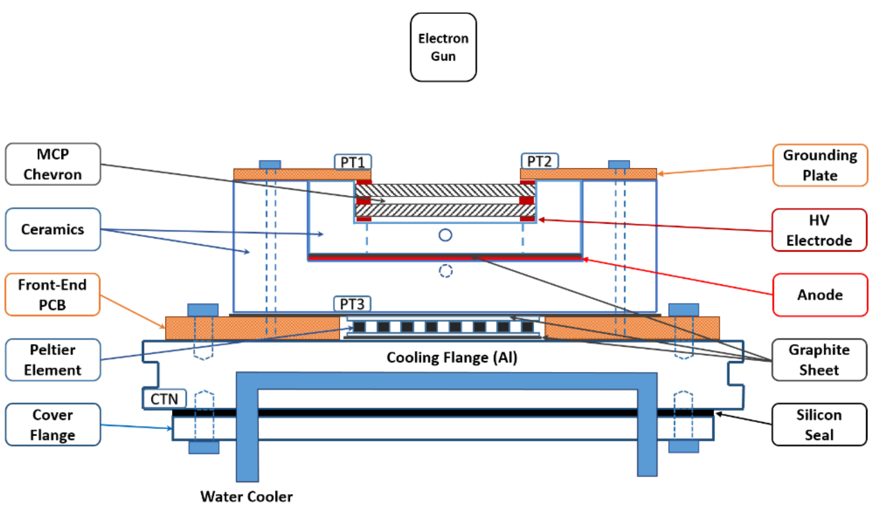


Figure 3. Setup used for measuring the gain of the MCP chevrons.

The test setup is depicted in figure 3 above. It is composed of an assembly of two boron nitride ceramics, a front-end electronics board, a Peltier element between the larger ceramic which contains an anode to collect charges from the MCP chevron and the flange in aluminum which acts as a sink. The MCP chevron is assembled inside the smaller ceramic which contains an electrode for the high-voltage bias. A grounding plate is used to hold the MCP chevron inside the smaller ceramic. The setup parts are shown on figures 4 below.

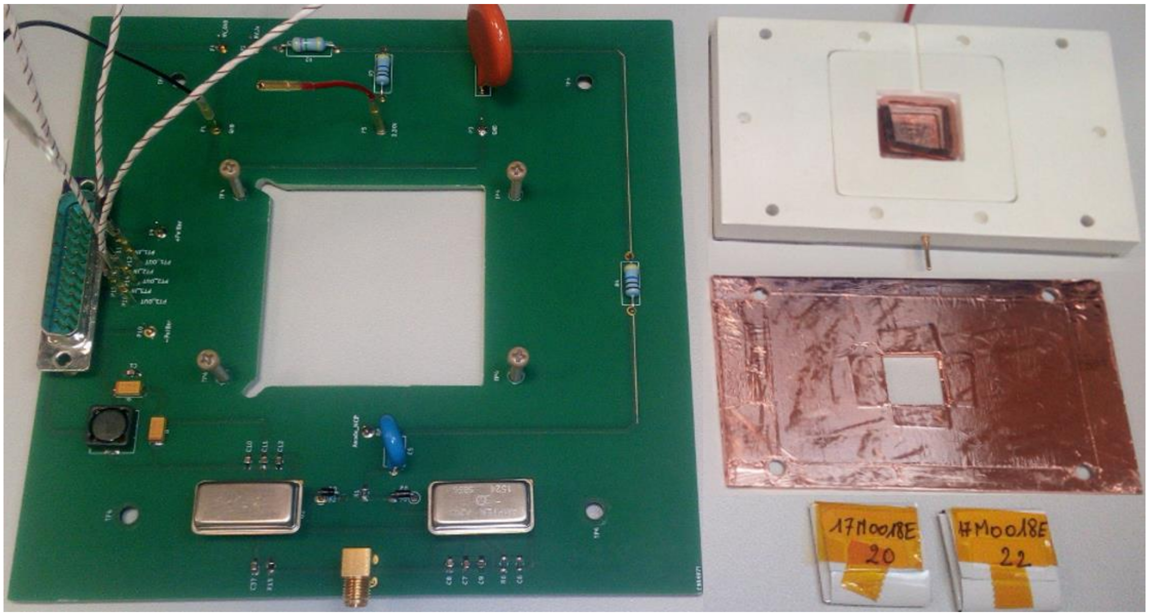
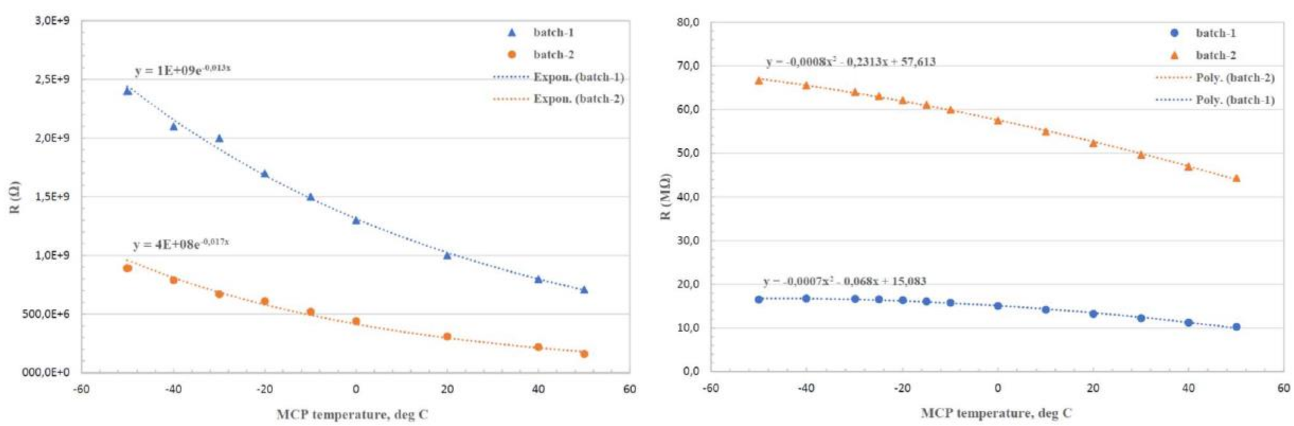


Figure 4. View of the setup parts showing the front-end electronic board, the ceramics, the grounding plate and the MCP samples.

3. EXPERIMENTAL RESULTS

3.1 Variation of the resistance of the MCPs with temperature

The resistances measured with the small and full-size plates are shown on figure 5 below. We can see that the resistance of the small plates varies exponentially while the variation of the resistance of the full-size plates with temperature is polynomial. This is due to the self-heating effect whose influence increases with the size of the MCPs.



(a) (b)

Figure 5. Variation of the resistance versus temperature of four MCP chevrons taken from two different batches. The plot (a) represents data from MCP samples 18x18 mm² and the plot (b) data from full-size MCPs 58x90 and 48x140 mm².

3.2 Variation of the gain of the MCPs with temperature

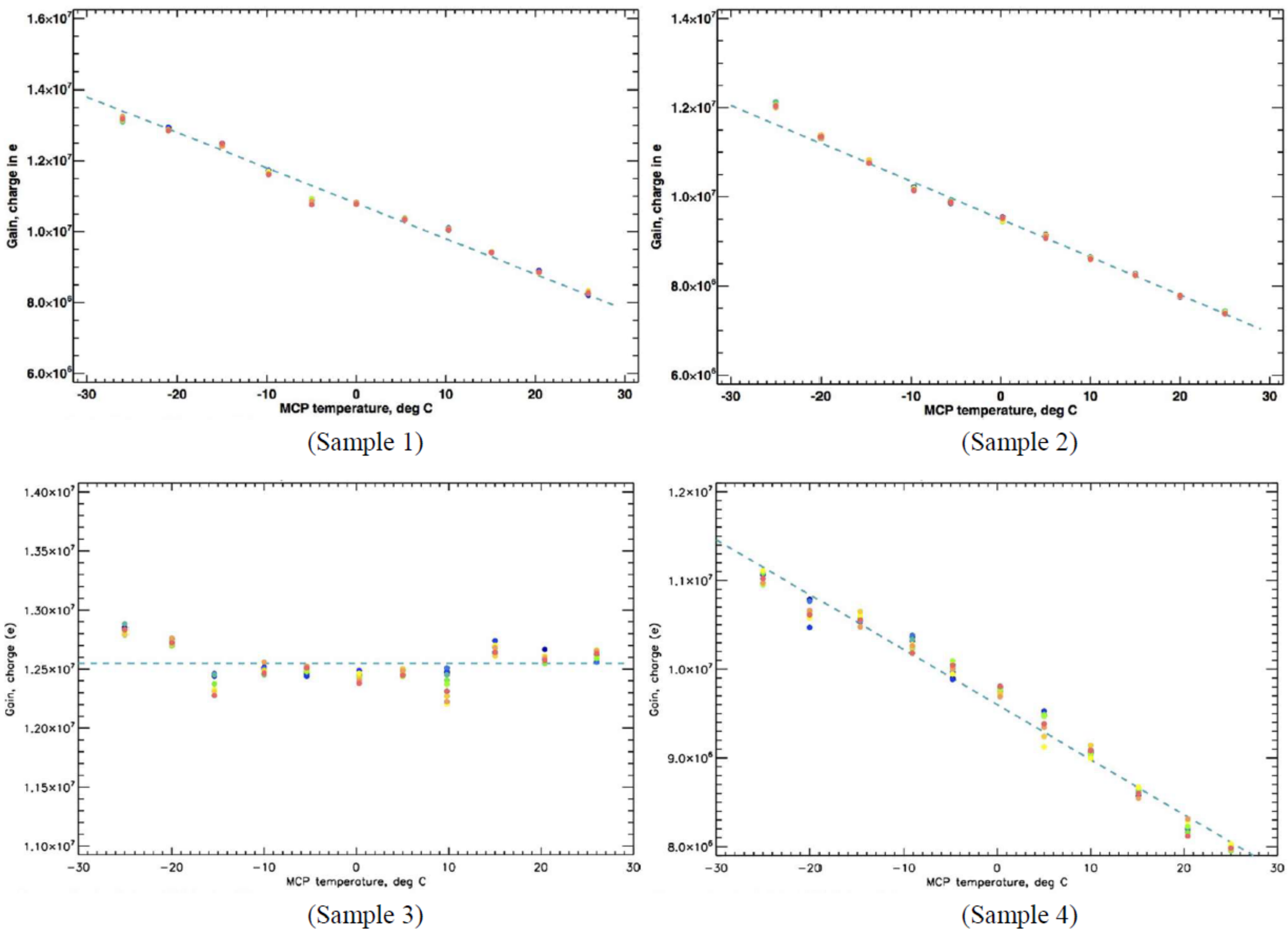


Figure 6. Variation of the gain of four samples of MCPs as a function of temperature. Each sample is taken from different batches. Samples 1 and 2 are from PHOTONIS USA and sample 3 and 4 from PHOTONIS France.

The variation of the gain measured for four MCP samples in chevron configuration is shown on figure 6 above. The samples used and the test conditions are those described in table 2 above. We can see that the gain of most of the samples tested decreases when the temperature increases except for the gain of sample 3 from PHOTONIS France with the highest resistance (1000 MΩ) and whose gain seems to be constant with temperature. Otherwise, the variation of the gain of sample 1 and sample 2 from PHOTONIS USA and sample 3 from PHOTONIS France is respectively, -1.3 %/ °C, -1.1 % / °C and -0.85 % / °C.

4. DISCUSSIONS AND CONCLUSIONS

We have presented the results of the resistance measurement we performed in the temperature range -50 to +50 °C and the gain measurement we performed in the temperature range -25 to +25 °C using different MCPs from PHOTONIS France and PHOTONIS USA dedicated for the JENI (PEP package) instrument that will be onboard of the near-future ESA Jupiter Icy moon Explorer (JUICE) mission. Our measurements show that the resistance of the MCP detector can be influenced by the self-heating effect depending on its characteristics and size. Now, it is very important to know how the resistance of the MCP detector behaves with temperature to properly size the high-voltage source or, conversely, to choose a technology according to the size of the MCP detector and the maximum current that the high-voltage source can supply. For that reason, it is preferable to use full-size MCPs in their final configuration to characterize their resistance. Two other important characteristics of MCPs are their gain and their lifetime which represents the total charge that can be extracted from them. Since the environment of Jupiter is very severe, the instruments on board of JUICE will operate in the presence of high-energy particles that will induce background noise on the MCP detectors due to the shielding of the instruments against radiation. Therefore, the background noise in the Jovian environment represents a crucial issue for the MCP detectors whose gain can be degraded prematurely if too much charge is extracted from them due to the induced particles. While it is well-known how the gain of the MCP detector can be optimized by acting on parameters such as the applied voltage, the length-to-diameter L/D ratio, the electrode penetration depth or the bias angle, ours measurements show that the gain of the MCP detector can increase when the temperature decreases depending on its technology; which is consistent with previous studies. This is an important result which can be used to optimize the gain performance and the lifetime of the MCP detector.

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