Gas gain study of a large-size multilayer Micromegas

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Abstract. The results of the study of a large-size, multilayer Micromegas detector with X-ray source Cd-109 are discussed. The detector consists of 4 layers, each of them is a Micromegas detector with resistive anode and strip-based read-out structure. The gas volume of the chamber is split to 4 parts interconnected in 6 points. Results of the measurements of the gas gain curves and the 1st Townsend coefficient as well as the E_amp/E_drift characteristics are presented and discussed. The detector presented a non-negligible gas leak, affecting the reported results. The influence of the leak on operation of the module is estimated.

1. Introduction

The Micromegas detector is a planar gaseous detector working in proportional gas gain regime [1]. The gas volume of the detector is formed by the cathode and the anode and divided by conductive mesh in two parts. The gap between the cathode and the mesh is typically a few millimeters wide. Under influence of the electric field of several hundred V/cm between the cathode and the mesh the primary ionization electrons drift to the mesh. The field between mesh and anode is ~ 50 kV/cm. Approaching the mesh, the primary electrons pass through it into the amplification gap. In the amplification region the primary electrons accelerate and reach the energy enough to ionize the gas that leads to electron avalanche development. The amplification gap is very narrow (~ 100 μm) and the amplification field is constant that improves ion collection time and increase the detector rate capability.

![Operating principle of a Micromegas detector](image1.png)

**Figure 1.** Operating principle of a Micromegas detector [2].

The studied Micromegas detector is full-size prototype of ATLAS New Small Wheels (NSW) Micromegas module [2]. The wheels will be installed behind the calorimeter end-caps in the solenoid

![Photo of the studied Micromegas module](image2.png)

**Figure 2.** Photo of the studied Micromegas module.
magnetic field. Micromegas for NSW is designed to track muons in magnetic field up to 0.3 T in high background rate up to 14 kHz/cm² providing spatial resolution better than 100 μm.

The studied Micromegas chamber is prototype of LM2 module for NSW. The prototype consists of 4 layers, each of them is a Micromegas detector with resistive anode and strip-based read-out structure. The drift gap of each layer is 5 mm wide, the drift voltage working point is -300 V. The used micromesh has 71 μm pitch with wire diameter of 30 μm. The mesh is attached to the cathode frame and grounded.

The amplification gap is defined by Piralux® pillars of 120 μm height with deviations of a few microns over the layers. A number of various defects are present on the anode PCBs that significantly change the amplification gap in the local area. Those defects that decrease the amplification gap were passivated with insulating Kapton® film to avoid discharges in these regions.

The amplification voltage is applied to resistive layer composed of strips while the copper readout strips are used as a readout. Typical amplification voltage is 580 V.

The gas mixture Ar(93%)/CO₂(7%) was chosen to provide high detection efficiency of relativistic muons and low aging under high irradiation during long period.

2. Experimental method

The measurements were carried out at CERN RD51 laboratory with temperature and air pressure monitoring. During the measurements, temperature was staying constant at 21.5°C. The module was working at atmospheric pressure with overpressure of 3 mbar that was kept constant by a constant gas flow of 5 l/h. During the measurements the gas pressure was 1.016 bar.

![Figure 3. Typical spectrum from the layer 3.](image1)
![Figure 4. Typical spectrum from the layer 4.](image2)

Drift and amplification voltage scans were carried out with Cd-109 X-ray source (22.6 keV). Typical spectra from layer 3 and layer 4 are shown on figure 3 and figure 4. Comparing the spectra one can see that the layer 3 has poorer efficiency, signal amplitude and energy resolution. Behavior of the layer is considered and discussed below.

The Kα peak of excited copper (8.1 keV) is also visible on the spectra. It was also used in the calculations of gain.

3. Experimental results

3.1. Drift voltage scan

During the drift voltage scan the amplification voltage on the layer 4 was kept at 580 V, and for layer 3 it was reduced to 560 V due to high discharge rate at 580 V. Results of the drift voltage scan are shown on figure 5. According to the mesh transparency simulation [3 figure 4], the curves obtained for layer 4 corresponds to the transparency for the chosen micromesh. Maximum of the curves from layer 3 are shifted to the right w.r.t. the curves from layer 4. This assumed to be related to air contamination at the layer 3.
Using the mesh transparency simulation [3] the corresponding maximal efficiency of primary electrons collection was estimated and the collection efficiency at -300 V was calculated. For layer 3 the collection efficiency is 82% and for layer 4 is 90%.

3.2. Gas gain measurement
Amplification voltage scan was performed at constant drift voltage -300 V in two points on layer 3 and on layer 4. The gain is calculated using the formula

$$G = \frac{Q \omega_{Ar-CO_2}}{E \delta}, \quad (1)$$

where $\delta$ is the primary electrons collection efficiency and $\omega_{Ar-CO_2}$ is ionization energy of the gas. For Ar(93%)-CO$_2$(7%) $\omega = 26.49$ eV. The scale of the ADC has been calibrated with the integrated charge.

Dependencies of gas gain on amplification field are shown on figure 6. One can see that the gain calculated by K$_\alpha$ peak is systematically higher than the one calculated by Cd-109 peak. This might be related to particular energy loss appearing when the photoelectrons have enough energy to pass through the drift gap and get out of the detection volume.

![Figure 5. Relative peak position vs drift field.](image1)

![Figure 6. Gain vs amplification field.](image2)

The gas gain at layer 4 reaches 8*10$^3$ that is close to the expected value of 10$^4$ [1]. The gain in layer 4 is limited by increasing of discharge probability at higher voltage. The gain curves at layer 3 has different slope with respect to the curves from layer 4 and to each other. This also point to a gas leak at the layer 3 that is located closer to the position 4.

3.3. 1$^{st}$ Townsend coefficient
Using the gain dependences, the 1$^{st}$ Townsend coefficient was calculated for both positions at both layers. The following parametrization of the Townsend coefficient was used [4]

$$\alpha = A_0 n \exp\left(\frac{B_0 n}{E_{amp}}\right), \quad (2)$$

where $A_0 = k_B A_1$, $B_0 = k_B B_2$, $k_B$ – Boltzmann constant, $n$ – gas number density. Using this parametrization the gas gain can be expressed as

$$G = \exp\left(\frac{A p g}{T} \exp\left(-\frac{B p g}{T V_{amp}}\right)\right), \quad (3)$$

where $T$ – thermodynamic temperature, $p$ – gas pressure, $g$ – amplification gap.
To extract the A and B parameters from (3) the expression was transformed to

\[ f = A \exp(Bx), \]  

where

\[ f = \frac{T}{\rho g} \ln G, \quad x = \frac{\rho g}{TV_{\text{amp}}}, \]  

The transformed gain dependences were fitted with function (4). Example of the fit is shown on figure 7. The values of the parameters obtained using Kα peak and Cd-109 peak are consistent within the errors. The weighted arithmetic mean of the parameters was calculated. The obtained parameters are collected in the table 1.

**Table 1.** A and B parameters of the 1st Townsend coefficient.

| Layer, Position | A, K⋅(bar⋅μm)^{-1} | B, K⋅V⋅(bar⋅μm)^{-1} |
|-----------------|---------------------|----------------------|
| Layer 3, Position 1 | 79 ± 7 | 1949 ± 128 |
| Layer 3, Position 4 | 58 ± 6 | 1547 ± 134 |
| Layer 4, Position 1 | 111 ± 6 | 2345 ± 77 |
| Layer 4, Position 4 | 95 ± 4 | 2115 ± 62 |

**Figure 7.** Example of fitting the gain data with function (4).

### 3.4. Discussion

The measured parameters of the Townsend coefficient differ from each other both between the layers and between the positions on one layer. As the parameters depends only on the composition of the gas mixture, the results confirm the assumption that layer 3 has leakage close to the point 4 – top left corner on figure 2. As far as all the layers are interconnected, oxygen molecules reach layer 4 that is indicated by lower values of the parameters at the position 4.

The values at position 1 on the layer 4 are the least affected by the oxygen contamination. These values are comparable to the ones provided in [5]: \( A = (111.2 \pm 0.6) \text{ K⋅(bar⋅μm)}^{-1}, \ B = (2196 \pm 7) \text{ K⋅V⋅(bar⋅μm)}^{-1}. \)
4. Conclusion

Results of the measurements of the gas gain of the multilayer Micromegas module are presented. It is shown that gain reaches $8 \times 10^3$ at the layer 4. The measurements of the $E_{\text{amp}}/E_{\text{drift}}$ characteristics and the 1st Townsend coefficient parameters showed the presence of the gas leak at the layer 3 close to position 4. Assuming the measurements at the layer 4 position 1 to be the least affected by the oxygen contamination the 1st Townsend coefficient parameters measured with the module are $A = (111 \pm 6) \text{K} \cdot (\text{bar} \cdot \mu\text{m})^{-1}$ and $B = (2345 \pm 77) \text{K} \cdot \text{V} \cdot (\text{bar} \cdot \mu\text{m})^{-1}$.

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