Operation of a novel large area, high gain, single stage
gaseous electron multiplier

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ABSTRACT: The operation of a novel large area micro-patterned gaseous electron multiplier, made
from a 125 micron thick copper claded kapton foil, the COBRA_125, is presented. The COBRA_125 is equipped with 3 independent electrodes which allow to establish 2 independent multiplication regions in a single micro-patterned gaseous electron multiplier. We report on the operation of a COBRA_125 with an active area of 100×100 mm². Charge gains above $10^4$ and energy resolutions in the range 18%–20% were achieved in a mixture of Ar-CH₄ (90%–10%) by irradiation with X-rays from $^{55}$Fe source. Gain and energy resolutions were stable over the detector area, with maximum deviation from the average values of 8% and 15%, respectively.

KEYWORDS: Gaseous detectors; Micropattern gaseous detectors (MSGC, GEM, THGEM, RETHGEM, MHSP, MICROPIC, MICROMEGAS, InGrid, etc); Gaseous imaging and tracking detectors

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1 Introduction

High gain gaseous electron multipliers can be implemented by cascading several individual GEM foils [1]. This is usually accomplished by using 2 or 3 foils stacked in a cascade, with separations of few mm between each foil. The primary electrons resulting from the conversion of the incoming radiation in the gas (or photoelectrons extracted from a photocathode in the case of Gaseous Photomultipliers, GPM [2]) are amplified on the first GEM of the cascade, from which a fraction of the resulting electrons are extracted and focused into the following GEM, in which the multiplication process is repeated. Although high gains are achievable for several gas mixtures [2], the use of cascaded GEM foils has however some inconveniences. On one hand, the maximum voltage difference across the cascade increases with the addition of GEM foils to the cascade, and can reach figures of the order of few kV [2, 3], which puts strain on the electrical connectors causing applied voltage instabilities and leakage currents. In addition to the polarization of each of the GEM foils, the voltage difference across the cascade also includes the necessary potentials to establish the electric transfer field between each of the elements of the cascade. For instance, in a 2-GEM detector, requiring a total polarization of 1.81 kV (excluding drift region), only 43% of this voltage is used to directly polarize the GEM foils, in which the electron avalanches take place, with the remaining being used to establish the electric fields in the transfer and induction regions [4]. An optimization of the transfer field between GEMs of the cascade is also required, which takes into account the inherent conflicting requirements between electron extraction from the holes of one GEM and electron focusing into the holes of the next GEM [5]. As so, the charge gain achievable with a cascade of GEM foils is far from the product of the individual GEM gains. Another potential drawback is related with detector thickness; although the GEM foil thicknesses are negligible, the gaps between consecutive GEMs are of few mm. This restricts their implementation on applications requiring a few-millimetre thin sampling detectors such as Digital
Hadron Calorimetry (DHCAL) [6]. To assure uniformity over the entire detector area, dictates the constancy of the gaps within the cascade over the entire detector area, which is a challenge in the production of large area GEM based detectors [7]. In addition, the larger distances travelled by the electron clouds implies larger electron diffusion, which negatively impacts the achievable position resolution and may be a problem for some applications [8, 9].

High gain single element gaseous electrons multipliers such as the MHSP [10] or the THCOBRA [11] combine two independent multiplication regions in a single micro-patterned gaseous electron multiplier (MPGD) and are an alternative to GEM cascades. These alternatives provide a simple geometry which allows electron multiplication in a hole (similar to the one of GEM foils), followed by a second multiplication stage in the same structure. For example, in the case of the MHSP, the first gain element is the hole structure, followed by a Micro Strip Gas Chamber (MSGC) like multiplication stage, with 2 independent sets of electrodes (figure 1, left). Whilst in the MHSP these electrodes are linear, in the THCOBRA (figure 1, right) they are curved. In either case, the holes cross the copper in the middle of the cathodes and the anodes are placed between two consecutive cathodes. The electrons which are multiplied inside the holes are extracted and further multiplied in the region between cathode and anode. The resulting charge is collected at the anodes.

![Figure 1](image.png)

Figure 1. Detail photos of the MHSP (left) and THCOBRA (right) bottom sides.

The above mentioned setup allows high gains in a single element since the multiplication region at the holes is immediately followed by another, independent, multiplication stage.

The main differences between THCOBRA and the MHSP are the insulating material used between the two copper layers and their dimensions. THCOBRA uses a 400 micron thick G10 plate whereas a 50 micron thick Kapton foil is used in the fabrication of the MHSP. While, thanks to thick G10 plate, the THCOBRA is an extremely robust gaseous electron multiplier, it is not suitable for operation in detectors with high purity requirements, such as noble gas sealed detectors, due to the large outgassing and intrinsic radioactivity of the G10. THCOBRA elements also require higher polarization voltages to achieve charge multiplication due to their larger thickness. On the other hand, the MHSP, although sharing the same constituent materials and production techniques as the GEM, was never implemented over large areas, due to the difficulty in the production of the thin (10–20 micron wide) anode strips. The presence of the thin electrodes made it very prone to damage caused by electrical discharges. As a consequence of these technical difficulties, it has been impossible to implement a high gain, large area, robust, single element MPGD, compatible with low-outgassing applications.
Figure 2. (left) Micro-photography of the COBRA_125 bottom side. (right) Operating principle of the COBRA_125; the primary electrons are drifted to the holes of the COBRA_125, where they experience a first (hole like) multiplication stage, controlled by the voltage difference, $V_{\text{HOLE}}$, between the top and cathode electrodes. The resulting charge is then extracted from the holes and further multiplied in the region between the cathodes and anodes, by means of the voltage between these two electrodes, $V_{\text{STRIPS}}$. The final charge is collected at the anodes.

2 The COBRA_125

We have developed a novel MPGD which improves some issues of the MHSP; following the experience with 100 micron Kapton thick GEM foils, which showed immunity to damaged caused by discharges [12], we have implemented the COBRA_125, made from a 125 micron thick Kapton foil, equipped with 60 micron wide electrodes (figure 2). The COBRA_125 used in these measurements was produced at CERN workshops, with an active area of $10 \times 10 \, \text{cm}^2$. The bi-conical holes, with larger and smaller diameters of 120 micron and 60 micron, are etched in a regular pattern on the copper and Kapton. While the top side of the COBRA_125 is a continuous electrode (similar to the one in GEM’s) the bottom side is equipped with 2 independents sets of electrodes (figure 2, left). One of these (the cathodes), surrounds the holes while the other (anodes) are placed in between each pair of consecutive cathodes, separated by a distance identical to their thickness (60 micron).

3 Experimental setup

3.1 COBRA_125 polarization

By applying a voltage difference, $V_{\text{HOLE}}$, between the top (GEM-like) electrode and the cathode, an electrical field is established inside the holes, responsible for the electron avalanches in this region. The resulting charge is then extracted from the holes and further multiplied in the region between the anode and the cathode due to an additional voltage difference, $V_{\text{STRIPS}}$, established between
these two electrodes. The resulting charge is collected at the anodes of the COBRA_125. The total voltage applied across the COBRA_125, $V_{\text{TOTAL}}$, is the difference between the voltage applied to the anodes and top electrodes, $V_{\text{ANODE}}$ and $V_{\text{TOP}}$, respectively.

The induction mesh, located underneath the COBRA_125 in figure 2 is held at ground potential, ensuring high electron collection efficiency into the anodes.

Prior to its assembly in the detector, and after some hours at a temperature of 40°C under low humidity conditions, the dark currents between top and cathodes and between cathodes and anodes were measured and found to be, respectively, 2 nA and 5 nA, for $V_{\text{HOLE}}$ and $V_{\text{STRIPS}}$ of 300 V.

3.2 Detector setup and data acquisition

The COBRA_125 was placed in a stainless steel chamber, equipped with high voltage and signal feedthroughs. The chamber, with an inner volume of $20 \times 20 \times 5.5 \text{ cm}^3$, was sealed using a Viton O-ring with a stainless steel plate (4 mm thick). Depending on the type of measurements made, in current or pulse mode, the stainless steel plate was equipped either with a 12 $\times$ 12 cm$^2$ aluminized Mylar™ foil (25 μm thick) for the pulse mode measurements or with a 55 mm diameter, 4 mm thick, fused silica window, for the current mode measurements. In this later mode of operation, a 250 nm CsI photocathode was deposited on another fused silica window, pre-evaporated with a 100 Å aluminium layer, which was placed 9 mm away from the COBRA_125, replacing the drift mesh depicted in the scheme of figure 2. In the pulse mode operation, the drift region, 9 mm deep, was established by the top electrode of the COBRA_125 and the drift mesh (made from a 80 μm diameter stainless-steel wire with 900 μm spacing), as depicted in figure 2.

The detector was operated in a mixture of Ar-CH$_4$ (90%-10%), continuously flowing through the detector at a rate of 2 litres per hour. The pressure on the detector was maintained slightly above atmospheric pressure and the detector was separated from the atmosphere by a small layer of vacuum pump-oil where the gas exhaust tube was submersed.

The electrodes of the COBRA_125 were independently biased using CAEN N471A power supplies. A ramp up rate of ~5 V/sec was manually established for the polarization of the electrodes. As a precaution, the maximum current on each channel was limited to 120 nA, to ensure protection to the electrodes of the COBRA_125 in case of discharge.

In the pulse mode operation the primary electron clouds were produced by conversion of 5.9 keV X-rays from a $^{55}$Fe source. The Kβ emission at 6.5 keV was attenuated with a Cr filter placed between the source and the detector entrance window. The primary electron clouds were focused into the holes of the COBRA_125 by an electric field, $E_{\text{DRIFT}}$, established between the drift mesh and the top electrode of the COBRA_125. The final electron clouds were collected at the anodes of the COBRA_125 using a charge sensitive pre-amplifier (Canberra 2004) whose output was fed to a linear amplifier (Tennelec 243) with peaking and shaping time constants of 2 and 4 microseconds, respectively. The signals from the linear amplifier were digitized by a 1024 channel ADC (Nucleus PCA). For each dataset, acquired over a period of 120 seconds, a single Gaussian curve was fitted to the main peak (figure 5). The median and spread of the Gaussian fit were used in the energy resolution calculation and charge gain estimation, as a function of the applied voltage.

Charge gain calibration was performed in current mode operation. The Mylar™ foil used as entrance window for the X-rays in the pulse mode measurements was replaced by a fused silica window and the discrete $^{55}$Fe X-ray source by a pen-style continuous HgAr UV calibration lamp.
The drift electrode in figure 2 was replaced by an additional fused silica window, vapor deposited with a 250 nm CsI photocathode on top of a 100 Å layer of Al, which allowed an electric field, $E_{\text{EXTR}}$, to be established between the fused silica window and the top electrode of the COBRA_125. $E_{\text{EXTR}}$ was responsible for the primary electron extraction from the CsI photocathode. Depending on the electric field at the surface of the photocathode and on the UV lamp intensity, primary currents of few tenths of pA were measured, for null electric fields across the holes and between the strips of the COBRA_125. While $E_{\text{EXTR}}$ was kept constant throughout the measurements, the UV lamp intensity was adjusted in order to keep the currents at the electrodes of the COBRA_125 below the limit set on the CAEN N471A power supplies ($\sim$120 nA). In this mode of operation, the charge gain is taken directly as the ratio of the current measured at the anodes of the COBRA_125 and the primary current emitted by the photocathode; both these currents were subtracted from their dark values, i.e. the values measured without photocathode illumination. The current at the photocathode was measured with an analog electrometer (Keithley 610C) while the anodes current was determined by measuring the voltage drop across a 12 M$\Omega$ resistor, connected in series between the anodes of the COBRA_125 and its corresponding power supply.

4 Results

4.1 Charge gain

Figure 3 presents the centroids of the pulse height distributions obtained by irradiating the COBRA_125 with X-rays from a $^{55}$Fe source, as a function of the $V_{\text{STRIPS}}$, (figure 3, left) and $V_{\text{HOLES}}$ (figure 3, right). The charge gains, measured in current mode using the CsI photocathode and HgAr lamp as described above, are also overlapped in figure 3 (left). The charge gains in pulse mode were calibrated by normalizing the centroids of the Gaussian peaks in the pulse height distributions to the gain obtained in current mode, for the same voltages applied to the COBRA_125. Maximum gains above $10^4$ were achieved for stable operating conditions (before the onset of discharges).

![Figure 3](image_url)

**Figure 3.** Charge gains achieved with COBRA_125 in Ar-CH$_4$ (90–10), as a function of $V_{\text{STRIPS}}$ (left) and $V_{\text{HOLES}}$ (right), for different values of $V_{\text{HOLES}}$ and $V_{\text{STRIPS}}$, respectively. Maximum charge gains achieved were $3\times10^2$ in pulse mode (using the $^{55}$Fe source). On the left, also presented are the charge gains in current mode, recorded for matching voltages as the ones in pulse mode, and used for their calibration. The maximum gain in current mode was $6\times10^4$. 


4.2 Energy resolution

Figure 4 presents the energy resolution (\%FWHM) obtained by fitting a Gaussian to the centroids of the pulse height distributions that have already been used to extract the charge gains in pulse mode presented in figure 3.

![Energy resolution graph](image)

**Figure 4.** Energy resolution achieved with the COBRA_125 in P10, as a function of $V_{\text{STRIPS}}$ (left) and $V_{\text{HOLES}}$ (right).

In figure 5 we present an example of a typical pulse height distribution recorded with the COBRA_125 by irradiation with the $^{55}\text{Fe}$ source. Clearly visible features are the full energy peak (at 5.9 keV), the argon escape peak at 2.9 keV and the electronic noise, which in our setup was below 1 keV. The pulse height distribution features an energy resolution of 18.1\% (5.9 keV, FWHM) and a clear separation of the argon escape peak.

![Pulse height distribution graph](image)

**Figure 5.** Typical pulse height distribution recorded with the COBRA_125 by irradiation with the $^{55}\text{Fe}$ source for $V_{\text{HOLES}} = 630$ V and $V_{\text{STRIPS}} = 130$ V. Acquisition time was 120 s.
4.3 Uniformity

The results presented in the studies above were obtained by irradiating a small portion of the detector, in its center. In order to evaluate the detector uniformity over its full sensitive area, a series of 100 measurements were performed with a collimated (~.785 mm$^2$) $^{55}$Fe source, in a regular 10×10 matrix (10 mm spaced), uniformly covering the full 100×100 mm$^2$ area of COBRA_125. For each point, corresponding to a different (x,y) location, a 120 s dataset was taken, allowing to determine the energy resolution and charge gain for that specific coordinate. The results are presented in figure 6 and show that no region of the COBRA_125 presented a charge gain or energy resolution deviation from the average values of more than 8% and 15%, respectively. The irradiation was performed at moderated $V_{TOTAL}$ across the COBRA_125, to which corresponded an average charge gain of $1.4 \times 10^3$ and average energy resolution of 20.4%.

The results shown in figure 6 represent an improvement in charge and gain uniformity across the whole detector area when compared with previous studies made with cascades of 3-GEM foils [13, 14].

![Figure 6](image)

**Figure 6.** Charge gain (left) and energy resolution (right) over the COBRA_125 area for $V_{STRIPS} = 250$ V and $V_{HOLES} = 590$ V. Acquisition time for each dataset was 120 s. Average energy resolution was 20.4% and charge gain $1.4 \times 10^3$.

5 Conclusion

We presented the results of the operation of a novel gaseous electron multiplier, the COBRA_125. This detector was fabricated with a 125 micron thick, copper cladded, Kapton foil and is equipped with 3 independent sets of electrodes, which allow to establish 2 independent multiplication regions. This novel configuration results in maximum gains of $3 \times 10^4$ when irradiated by X-rays from a $^{55}$Fe source and operating in Ar-CH$_4$ (90%-10%). This figure is equivalent to the gain reported in [1] $3.4 \times 10^4$, achieved in similar conditions, but using three GEM foils in cascade. Typical values of energy resolution (%FWHM) recorded were found to be in the range 18%-22%. Operating the COBRA_125 in current mode, with the primary electron being extracted from a reflective photocathode irradiated by an ArHg UV lamp, result in gains slightly higher, $6.6 \times 10^4$, which in this case are an order of magnitude lower than the ones achieved with a 3-GEM under similar conditions [2].
The gain and energy resolution are fairly constant over the 100×100 mm² of the COBRA_125, with deviations not larger than 8% and 15%, respectively. This compares favorably with cascaded GEM detectors: previous results of our investigations with a double GEM cascade [12] showed gain and energy resolution variations of 10% and 20%, while in [13, 14] the lowest values of gain and energy resolution variations with a 3-GEM detector, were 19% and 23%, respectively. This improvement in the uniformity response with the COBRA_125 is attributed to the use of a single element, without the need to maintain a uniform separation between individual GEM foils as it is the case in 3-GEM detectors.

Although not measured in this work, the use of a single amplification element should also improve the electron diffusion, which is a desired trait in several applications in which position resolution is important [8, 9]. Future work will include position resolution measurements with a modified COBRA_125, which allows for 2D position determination by charge division with a resistive line [15].

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