First results on the GEM operated at low gas pressures

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We report on the properties of the Gaseous Electron Multiplier (GEM) operated at 10-40 torr isobutane and methane. We found stable operation at gains of a few thousands, fast response and effective photon-feedback reduction. The transmission of single electrons through the GEM apertures was studied. Ion-induced feedback, from a wire chamber following the GEM, was found to limit the total two-stage multiplication at high GEM gains. A stable double-GEM operation with reduced ion-feedback was demonstrated. Some applications are discussed.

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1. Introduction

The GEM (Gas Electron Multiplier) is a newly developed gaseous electron multiplier, described in details in references 1-3. It consists of a compact array of small apertures in a metal cladded thin insulator. A voltage difference applied across the GEM electrode leads to a strong dipole field inside the apertures. The GEM is usually inserted between planar electrodes which define the radiation-conversion and the electron collection volumes on its upper and lower sides, respectively. Radiation-induced electrons are strongly focused into the GEM apertures and undergo a multiplication of typically a few thousands [3]; they are transmitted to a further collection or multiplication element. The GEM has been investigated with many gas-mixtures at normal [3] and high [4,5] pressure. Large size electrodes are currently produced for high-rate particle physics experiments as a pre-amplification element, in conjunction with the more fragile MSGC [3,6]. The recently demonstrated high gain, with single- or double-GEM multipliers, permits the recording of MIP signals on patterned electrodes with no further amplification [3].

The study of GEM operation at low gas-pressure has been motivated by some applications which could benefit from the particular properties of such preamplifiers. For example, detectors based on single electron counting [7], developed for precise measurements of small energy deposits in gas, are employed in ultra-soft x-ray spectroscopy [8] and in nanodosimetry [9]. Their operation requires very efficient and reliable single-electron counting, which depends on high gain, fast signals and no photon or ion-induced electron feedback. Another example are detectors based on solid radiation converters coupled to gaseous electron multipliers [10], used for high-rate, parallax-free imaging of photons over a broad energy range, from UV to x-rays. Recent developments in gas-stable composite alkali antimonide photocathodes, may further extend the range of gas imaging detectors into the visible light [11,12]. Since radiation converters, e.g. CsI, often have high photo-sensitivity, the photon feedback limits the gas gain and distorts the recorded image. Positive ion back-flow to the converter should also be limited, since it strongly affects the converter's life time. A GEM electrode inserted between the converter and the main amplification element could considerably reduce both effects, improving the image quality and efficiency of the detectors.

We studied the operation of GEM with photon-induced single electrons from a CsI photocathode. We have studied gain and its limitations, stability, feedback processes, fast signal shape and electron transmission efficiency of the GEM. The last property is of crucial importance for our applications of single electron detection and counting.

2. Experimental procedure

Two different GEM elements were studied, in methane and isobutane at 10-40 torr: one produced by the CERN EST-MT printed circuits workshop and a commercial one from TECH-ETCH [13]. Both have apertures arranged in a rectangular pattern of $200\mu\text{m}$ pitch, on $50\mu\text{m}$ thick copper cladded Kapton. The apertures are of conical inner shape, with diameters (Kapton/Cu) of $80/130\mu\text{m}$ and $50/80\mu\text{m}$ for the CERN and TECH-ETCH GEMs, respectively. Figure 1 schematically shows the experimental arrangement. A CsI photocathode is irradiated through a UV-transparent window, by an Ar(Hg) UV lamp, producing single photoelectrons. They are focused onto the GEM by an electric field E_1 , multiplied and further collected onto the following mesh under electric field E_2 . With a proper choice of the potentials the pre-amplified electrons are transmitted to a multiwire proportional counter (MW) element. Signals are recorded from the MW anode wires ($20\mu\text{m}$ diameter, 1mm pitch) and currents can be measured on various electrodes as well as on the GEM upper and lower faces. Most of the measurements reported here were carried out with the TECH-ETCH GEM, at 40 torr isobutane. In part of the measurements a second GEM (CERN) was introduced between the first GEM and the photocathode, in order to study the operation properties of a double-GEM structure.

3. Results and discussion

Figure 2 shows the gain G measured in both GEMs, in isobutane, under intense UV illumination. It was obtained by measuring the current collected on the GEM's lower face with reversed E_2 (see fig. 1), and normalizing it to the current i_0 collected on the GEM's upper face when both GEM faces are at ground potential. ($E_1=11.7 \text{ V/cm}\cdot\text{torr}$ in both measurements). Gains of the order of a few thousands are feasible, though the electron mean free path is of tens of microns at these low pressures. It probably results from the multiplication extending well outside the apertures, due to the high reduced electric field even at distances of $100\text{-}200\mu\text{m}$ away from the GEM center, and due to the large electron diffusion at low gas-pressure.

The gain curves have no collection ($G=1$) plateau, pointing at the poor electron focusing and transmission with low field in the GEM apertures. The measured current is a product of the electron transmission and multiplication, which are inseparable.

Whereas the GEM gain is not sufficient to detect single electron pulses, these are detected at the anode of the MW element, with either fast (current) or charge preamplifiers. Figure 3 shows single-electron pulses recorded with a fast preamplifier (1ns rise time) from the MW anode, with GEM gain=250. The rise-time of 4 ns is identical to that recorded with a MW alone, at the same total gain. Therefore, the GEM can be employed as a fast pre-amplification element for single electron counting applications, without deterioration of the pulse properties. Figure 4 demonstrates the effective blocking of photon feedback when operating a UV-sensitive photocathode with the UV-transparent methane gas. Photon feedback, severely limiting the gain of a MW coupled to the CsI photocathode (top), is strongly attenuated by the geometrical shadowing of a GEM ($G=1$), inserted between the MW and the photocathode (bottom). The GEM itself, when strongly multiplying, may introduce some photon feedback. In a better UV quenching gas (isobutane) the photon feedback is completely undetectable when the GEM is introduced.

The total gain of a GEM+MW element, measured with a calibrated amplifier, is given in figure 5 as function of the MW anode potential, for several GEM gain values set according to the data of figure 2. In this configuration, however, we encountered a severe total gain limitation, due to a strong feedback process induced by positive ions; it appears at GEM gains above 100 and further increases with GEM gain. This is evident in the charge signals of Figure 6, depicting some ion-induced feedback pulses delayed by tens of microseconds. The delay depends solely on the value of the drift field E_2 , indicating that the secondary avalanches originate from the GEM electrode and not from the CsI photocathode. The exact mechanism responsible for the feedback signals is not yet understood, but we suspect that these are ions generated by the MW avalanche, which are strongly focused and accelerated by the high field inside the GEM apertures, and are sputtering its top face. Further study of the effect and its dependence on the electric field configuration is in course, to clarify this point and to allow for an optimization of the field lines to reduce the effect.

Electron transmission has been evaluated so far [14] by recording the currents collected on various electrodes under different field configurations. In this type of measurements the GEM gain and the electron transmission are inseparable. On the contrary, single electron pulse counting provide a direct and correct method to measure the transmission efficiency through the GEM. As stressed above, this is of crucial importance for the applications involving single electron counting and imaging, requiring the highest electron transmission from the conversion to the counting volume. The saturated shape of the single electron pulse-height distribution, observed by us in the MW+GEM mode of operation, ensured a reliable pulse counting with little sensitivity to electronic threshold. We measured the transmission efficiency

through the GEM by monitoring, under fixed UV irradiation, the counting rate of pulses at the MW anode and its variation with the drift fields and the GEM potentials. The total gain was kept constant by readjusting the MW gain for each GEM gain. Figure 7 shows the counting rate as function of GEM gain, with $E1=11.7 \text{ V/cm}\cdot\text{torr}$ and $E2=4\times E1$ (a “plateau” according to our current-based electron transmission data¹⁴). The counting rate does not show a plateau but rather keeps rising with the GEM gain. It is obvious that the focusing of electrons into the GEM apertures, as well as their extraction, depend on the detailed configuration of the field lines. In our particular setup the ion-induced feedback could also affect the pulse counting measurement at high GEM gains.

An improved configuration for studying the electron transmission is with a double-GEM, the first operated at high gain for efficient electron transmission while the second is operated at low gain to avoid ion feedback effects. For this purpose the CERN GEM was inserted between the TECH-ETCH GEM and the photocathode. Figure 8 shows charge pulses recorded from the MW anode in this configuration, clearly showing a reduced ion feedback even at total gain of 7×10^6 (to be compared with the data of fig. 6). The counting rate was measured as above, with $E1=11.7 \text{ V/cm}\cdot\text{torr}$, $E2=3\times E1$, ($E2$ is now the electric field between the two GEMs), $E3=E2$ ($E3$ being the field between the second GEM and the mesh) and with second GEM gain fixed at 10. The results are shown in figure 9. Again, there is no clear plateau in the counting rate dependence on the first GEM gain, and we suspect that the pulse counting is still governed by some secondary process, of either photons or ions.

4. Conclusions

We have shown that the GEM can be operated at low-pressure (10-40 torr) of pure hydrocarbon gases, both in single and double-GEM arrangements. Stable gains of a few thousands are achievable under these conditions. We have demonstrated the efficiency of the GEM in blocking photon feedback, of particular importance with solid or gaseous UV-sensitive photocathodes. We found that the GEM, as expected, is a fast amplification element, yielding current pulses with a few ns rise-time.

However, the application of the GEM in single-electron counting and imaging detectors is still questionable, due to some problems found in the course of this study. A severe gain limitation is induced by positive-ion feedback, which is present whenever the GEM is operated at high gain and is followed by a strong source of positive ions (i.e. any amplification element of high gaseous gain). The nature of this

ion-induced feedback should be further studied and ways should be found to reduce it. This could be reached by a better optimization of the field lines and the GEM aperture, by treating the GEM surfaces and by replacing the MW with other multipliers with reduced back-flowing ions, such as the MSGC, MGC and the MDOT. The electron transmission efficiency is still not fully understood, neither in single nor in double-GEM arrangements, and is a subject of further studies. A better optimization of the aperture geometry should have a strong impact on the field lines. In addition we are studying other detector/photocathode arrangement, as for example depositing the photocathode directly on the top face of the GEM. In that case the photocathode is totally shaded from the avalanche photons and no photon-feedback is anticipated.

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Figure captions

Fig. 1. The experimental setup with one GEM and a multiwire.

Fig. 2. Gain of CERN and TECH-ETCH GEMs in isobutane.

Fig. 3. Single electron pulses recorded with a fast (1ns rise time) preamplifier from the MW anode; GEM gain=250, total gain = 2×10^6 . The rise time is 4ns.

Fig. 4. Photon feedback in 40 torr methane. Left: a MW coupled to a CsI photocathode has an intense photon feedback and gain limited to $< 10^5$; right: a MW+GEM (gain=1), with reduced photon feedback and gain increase to 5×10^5 .

Fig. 5. Total gain of the MW+GEM, recorded from single electron pulses, for different GEM gains.

Fig. 6. Ion-induced feedback signals are limiting the total gain of the MW+GEM with GEM gains > 100 . top) MW gain = 10^4 ; middle) MW gain = 10^5 ; bottom) +20V leads to breakdown.

Fig. 7. Counting rate of single electron pulses on the MW anode under constant UV irradiation and fixed total gain, representing the electron transmission efficiency through the GEM apertures. $E1 = 11.7$ V/cm•torr; $E2 = 4 \times E1$.

Fig. 8. Single electron pulses from the MW preceded by a double-GEM amplification: 1st GEM gain=300, 2nd GEM gain=10, total gain = 7×10^6 . Ion-induced feedback is strongly reduced, as compared to figure 6.

Fig. 9. Same as figure 7, with double-GEM amplification preceding the MW. $E1 = 11.7$ V/cm•torr, $E2 = 3 \times E1$, $E3 = E2$.

figure 1

figure 2

figure 3

figure 4

figure 5

figure 6

figure 7

figure 8

figure 9