High gain operation of GEM in pure argon

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Abstract

We study the operation of the Gas Electron Multiplier (GEM) in pure Ar, in comparison to that in Ar-CO_2 mixture. In pure Ar, high GEM gains, of above 700 and 3000 for single and double GEM structures correspondingly, have been obtained. It is observed that the GEM effective gain and its charging-up are strongly affected by electric field values above and below the GEM. Applications to the development of non-ageing gas photomultiplier are discussed.

1. Introduction

It is generally accepted that gas devices cannot properly operate in a multiplication mode in noble gases, unless some quantity of the quenching gas (mostly organics) is added. Indeed, many years ago it was recognized that the maximum gas gain achievable in pure noble gases is rather low, due to a very early onset of secondary avalanche processes [1]. In particular, in pure Ar the gas amplification factor does not exceed a few hundreds in proportional counters [2,3] and a few tens in parallel-plate chambers [4,5].

The poor quenching properties of the noble gas molecule are due to the fact that it is monoatomic. This characteristic, howevere, is very useful if one is interested in non-ageing detectors: in contrast to molecular gases, in monoatomic gases nothing can decompose and thus induce ageing. Non-ageing gas fillings are of primary importance for the development of the gas photomultipliers [5-8], where even tiny amount of chemically active molecules created in an avalanche can destroy the sensitive photocathode layer. In particular, the stability of Ar-filled photodiodes was proved by exploiting a very large number of them in sound film reproduction [4].

During the last two years, a new gas device with internal amplification is being intensively developed: the Gas Electron Multiplier (GEM) [9-13]. GEM is a thin kapton foil metal-clad on both sides and perforated by a high density of micro-holes, inside which gas amplification occurs. It has been recently conjectured [13] that GEM can effectively operate in pure noble gases, since the quenching properties of the filling gas

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are less important compared to other gas amplification devices. Moreover, it was shown that the GEM operation in pure Xe almost does not differ from that in Xe-CO_2.

The possible reason is the effect of the avalanche confinement in GEM micro-holes [13]. One aspect of the effect is obvious: GEM is basically a multisegmented device, with suppressed feedbacks between holes. The second aspect is that, due to the high dipole field formed inside the hole [10], the avalanche is externally quenched when developing too far from the hole axis. Therefore, no matter what gas is used, the avalanche will be confined within a small space of a dimension of a few tens of microns, even at high gains, preventing the development of the discharge. In the present work we study the GEM operation in pure Ar, and compare to that in Ar-CO_2 mixture. We show that rather high gains are reached both for single and double GEM structures. We also investigate the effect of the electric field above and below GEM on its effective gain and charging-up.

2. Experimental setup and procedure

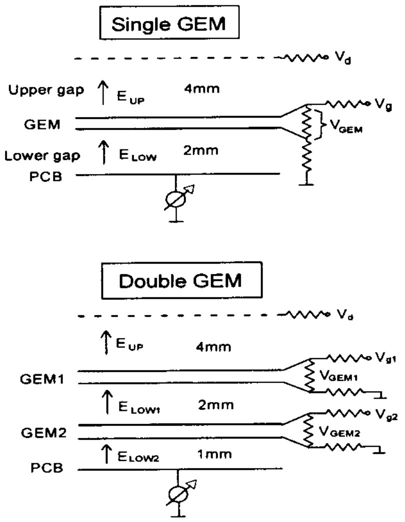

Figure 1 Schematics of a single and double GEM assembly with the appropriate notations.

All GEM devices investigated had a similar basic structure: 5mm copper electrodes were plated on 50μm Kapton; the hole diameters on the metal and center of Kapton were 80 and 50μm, correspondingly; the pitch was 140μm; the active area was 10×10 cm^2. Either a single or double GEM structure was coupled to a printed circuit board (PCB) with a 200μm pitch strip pattern, used as a readout element (Fig.1). For the single

GEM assembly, the upper and lower gap were 4 and 2 mm, correspondingly. For the double GEM assembly, the distance between GEMs was 2 mm and the upper and lower gap were 4 and 1 mm, correspondingly. The detector was flushed at atmospheric pressure with pure Ar or Ar-CO_2 (70-30).

Depending on the measurement to be performed, the PCB was grounded through a picoammeter or amplifier input. The high voltage was supplied to GEM electrodes through a resistive voltage devider. For the single GEM, the electric field below GEM, E_{LOW} , was proportional to the voltage applied across the GEM (GEM voltage, V_{GEM}): E_{LOW} = (4, 5 or 10 kV/cm)×(V_{GEM}/400V). The electric field above GEM, E_{UP} , was fixed.

In a symmetrical mode of operation of the double GEM, $V_{GEM1} = V_{GEM2} = V_{GEM}$ and the electric fields below each GEM were equal: $E_{LOW1} = E_{LOW2}$ = (4kV/cm)×(V_{GEM}/400V). In the asymmetrical mode of operation, the voltage on the first GEM was fixed, the lower field of the second GEM was the same as before, while the field bewteen GEMs was weaker, varying between 2.4 and 3.4 kV/cm.

The detector was irradiated with a 8 keV X-ray beam over an area of ~40cm^2 with a rate in a range between 10^1 and 10^4 mm^{-2}s^{-1}. In the pulse-height measurements,the exposed area was reduced to 2 mm^2 to prevent overloading of the amplifier.

The effective GEM gain was determined measuring either the pulse-height, with the help of a charge-sensitive preamplifier (integration time is 300ns), or the current from the PCB. Both techniques gave similar results. The absolute gain calibration was done at a point where both the current and the counting rate could be recorded simultaneously, assuming the initial charge in the upper gap generated by an X-ray conversion to be well known. The maximum gain is defined as the gain at the highest voltage at which there are still no micro-discharges during at least 1 min. he accuracy of the absolute gain values measured is estimated to be 20%.

3. Results

In a single GEM assembly, a large signal has been detected in pure Ar, with no afterpulses seen even at the highest gains.Fig.2 shows the GEM gains as a function of GEM voltage measured in Ar-CO_2 and in pure Ar at different rates; the last points correspond to the maximum safe gains obtained at a given rate. The data sets were measured at optimized upper fields E_{UP} and at different lower fields E_{LOW}.

One can see that the maximum gain attainable in pure Ar is about 700 at a rate of 10^2 mm^{-2}s^{-1} and large exposed area. The maximum gain drops down to 500 when increasing the rate by an order of magnitude. On the other hand, it can approach 1000 reducing the exposed area and slightly increasing the lower field, from (4 to 5 kV/cm)× (V_{GEM}/400V). This should be compared to 3000, the maximum gain value obtained in Ar-CO_2 at a similar ratio of lower field to GEM field.

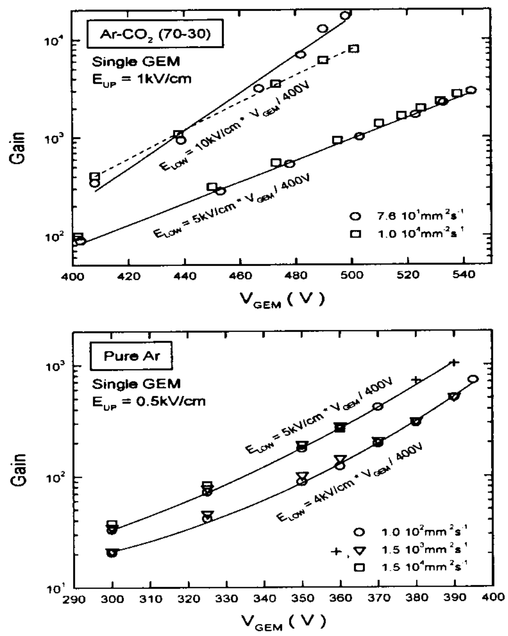

Figure 2 Effective gain of a single GEM as a function of GEM voltage measured in Ar-CO_2 and in pure Ar at different rates and different E_{LOW} . The exposed area of the detector was 40 cm^2 , except of the last two data points in Ar plot (cross symbols) where it was reduced to 2 mm^2 .

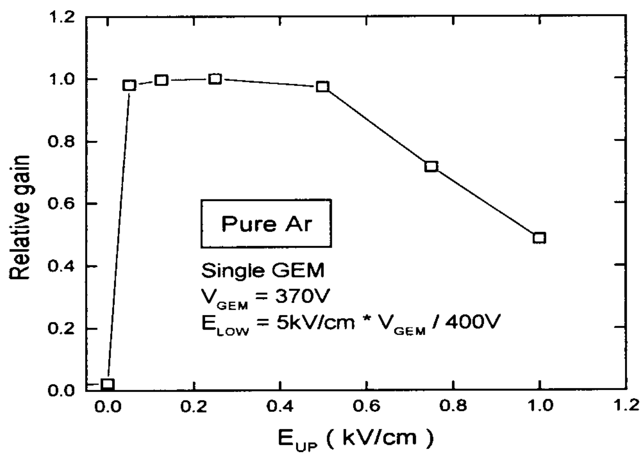

Figure 3 Relative gain of a single GEM in pure Ar as a function of the electric field in the upper gap.

It has been recently understood [10,11] that the values of the upper and lower electric fields play a crucial role on the effective GEM gain, i.e. on the shareing between the charge captured into GEM holes and the one transfered, after amplification, to the lower gap. This fraction is a function of the ratios E_{UP}/E_{GEM} and E_{LOW}/E_{GEM} (here E_{GEM} is the average field in GEM holes), of the electron diffusion and of the GEM geometrical transparency. Indeed, the higher the ratio E_{LOW}/E_{GEM}, the larger fraction of charge is transfered from holes into the lower gap. Conversly, the higher the ratio E_{UP}/E_{GEM}, the larger fraction of charge is lost due to termination of the field lines on the upper GEM electrode.

The last point is illustrated in Fig.3, showing the relative gain as function of the upper field: in pure Ar the optimal value of E_{UP} is below 0.5 kV/cm. In Ar-CO_2, the maximum value of E_{UP} is significantly larger: about 1.5 kV/cm [10]. The difference can be explained by the lower GEM operation voltage and probably by larger electron diffusion in pure Ar.

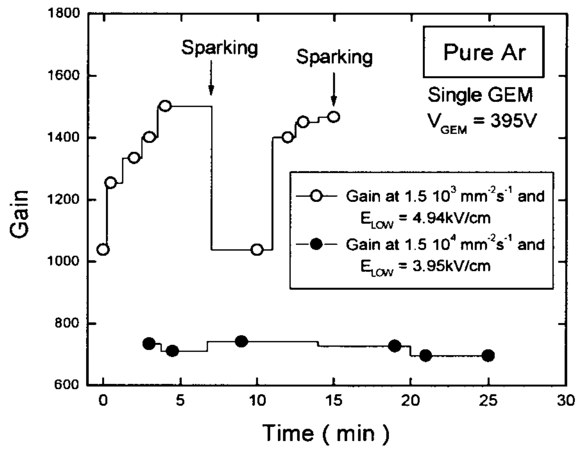

Figure 4 Effect of GEM charging-up in pure Ar. Shown is the GEM gains as a function of time measured at the same GEM voltages but at different electric fields in the lower gap. The exposed area is 2 mm^2 .

At too high values of the lower field, the lower gap starts to operate in a parallel-plate amplification mode. Though providing an additional gain, the parallel-plate mode results in two negative effects: gain non-uniformity over the area, and the charging-up of GEM. The latter is induced by a positive charge accumulation on the lower, bare kapton side due to ion feedback. Charging-up manifests itself in gain increase at low rates, due to enhancement of the local field in GEM holes, and in gain decrease at high rates, due to reduction of the lower field.

This is illustrated by Fig.2. At $E_{LOW} \leq (5\ kV/cm)\times(V_{GEM}/400V)$, below parallel-plate multiplication, there is no dependence of gain on the rate in both Ar-CO_2 and Ar. This is however not the case when increasing the lower field by a factor of 2 (see Ar-CO_2 plot): due to the parallel-plate mode contribution the gain drop can be as large as 50% at a rate of 10^4 compared to that of 10^2 $mm^{-2}\ s^{-1}$.

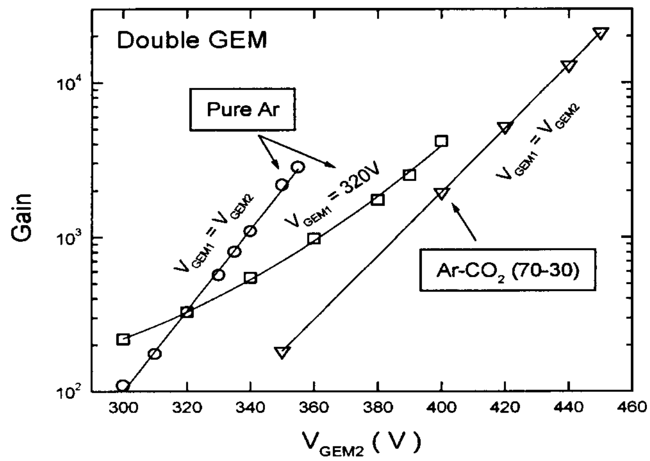

Figure 5 Effective gain of a double GEM in a symmetrical ($V_{GEM1} = V_{GEM2}$) and asymmetrical (V_{GEM1} is fixed) operation mode as a function of the voltage of the second GEM, measured in Ar-CO_2 and in pure Ar. The exposed area is $2mm^2$; the rate is 10^3 $mm^{-2}\ s^{-1}$. The upper fields are 1 and 0.4 kV/cm for Ar-CO_2 and pure Ar, correspondingly

We observed the effect of charging-up in pure Ar when the absolute value of the lower field reached 4.9 kV/cm, the value at which an avalanche multiplication starts in Ar [14,15]. Fig.4 shows the gain stability studied at the same GEM voltages but at different lower fields. One can see that while at E_{LOW} =3.95 kV/cm the gain is stable, at E_{LOW} = 4.94 kV/cm it grows with time until sparking. The spark discharge neutralizes a positive charge accumulated on GEM and initiates the next charging-up cycle.

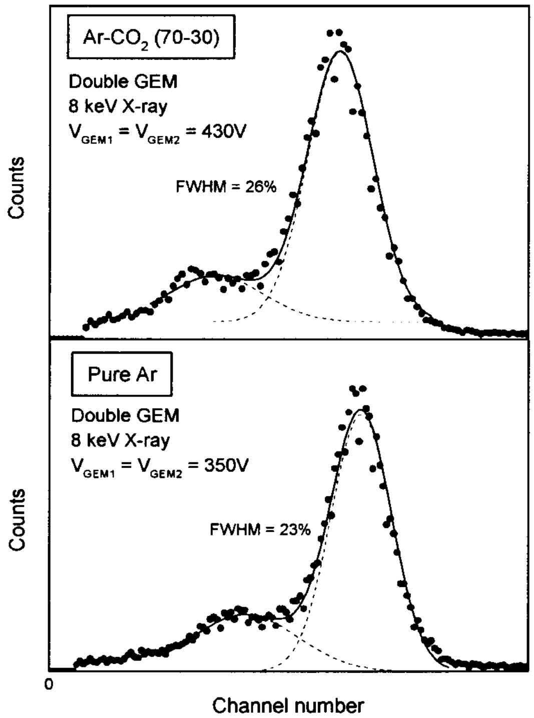

Figure 6 Pulse-height spectra in a double GEM for 8 keV X-rays, measured in Ar-CO_2 and pure Ar at effective gains of about 8000 and 2000, correspondingly. Other conditions are the same as those of Fig. 5.

Further increase of the maximum gain was obtained in a double GEM structure (see Fig.5). In a symmetrical operation mode, the maximum gain in pure Ar was about 3000, which should be compared to a value of 20000 obtained in Ar-CO_2 . Even higher gains, of above 4000, are reached if to operate in the asymmetrical mode, where the voltage on the second GEM is higher than on the first.

Rather satisfactory energy resolution in both single and double GEM was obtained in pure Ar. For example, Fig.6 shows the pulse-height spectra for 8 keV X-rays measured in a double GEM. Its energy resolution in Ar (FWHM=23%) corresponds to that in Ar-CO_2 .

4. Summary

In conclusion, we have demonstrated that rather large GEM gains, above 700, can be obtained in pure Ar in a single GEM, and very large gains, above 3000, in a double GEM, with reasonable energy resolution. This is exceptional for a proportional counter, and is probably a consequence of the avalanche confinement in GEM micro-holes.

It should be remarked that the GEM electrodes used in the present study had been previously used in a systematic investigation of discharge limits, and might here been slightly damaged. Therefore one would expect, that for a pristine GEM, the nominal maximum gain in Ar can be even higher, supposingly by a factor of 2-3.

We also expect that the further gain increase might be possible in Xe, provided that a similar tendency is observed in its mixtures with CO_2 .

An important observation is that optimal electric fields in Ar are significantly lower compared to those in Ar-CO_2 . In order to avoid charge losses and charging-up, the electric fields should be less than 0.5 kV/cm and 4.9 kV/cm above and below the GEM correspondingly. This is an outcome of the lower GEM operation voltage and the earlier beginning of the parallel-plate mode contribution.

The results obtained can find application mostly in the field of non-ageing gas devices. In pure noble gases the electron drift velocity is relatively small and the diffusion is large. Consequently, the Ar-filled devices may not be applied to track detection at high rates because of the large charge collection time. However, they may be relevant to the development of the gas photomultiplier where the parallax of the charge conversion point is absent. In particular, the gas photon detector, consisting of a series of GEMs coupled to a solid photocathode and operated in pure Ar, Kr or Xe, could be sealed, would be very long-lasting and would be not subjected to ageing. The life-time of such gas photmultipliers can even exceed that of the conventional vacuum phototubes, due to the lower ion energy in gas medium compared to vacuum and thus less effect of the ion bombardment of the photocathode.

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