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Letter to the Editor

GEM: A new concept for electron amplification in gas detectors

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Abstract

We introduce the gas electrons multiplier (GEM), a composite grid consisting of two metal layers separated by a thin insulator, etched with a regular matrix of open channels. A GEM grid with the electrodes kept at a suitable difference of potential, inserted in a gas detector on the path of drifting electrons, allows to pre-amplify the charge drifting through the channels. Coupled to other devices, multiwire or microstrip chambers, it permits to obtain higher gains, or to operate in less critical conditions. The separation of sensitive and detection volumes offers other advantages: a built-in delay, a strong suppression of photon feedback. Applications are foreseen in high rate tracking and Cherenkov Ring Imaging detectors. Multiple GEM grids assembled in the same gas volume allow to obtain large effective amplification factors in a succession of steps.

This note describes the basic concept and the first experimental observations realized with a novel structure for charge amplification: the gas electron multiplier (GEM). A more detailed study is in preparation [1]. The active element of GEM is a thin, self-supporting composite mesh, realized by photolithographic methods. A thin insulating polymer foil, metallized on each side, is passivated with photoresist and exposed to light through a mask; after curing, the metal is patterned on both sides by acid etching and used as self-aligning mask for the etching of the insulator, opening channels all the way through. For the measurements here described we have used a square mesh 50 mm on a side, realized on a 25 μm thick polymer sandwiched between 18 μm thick copper electrodes; the etching pattern has parallel rows of 70 μm wide holes 100 μm apart (Fig. 1). The fabrication technology, developed by the CERN Surface Treatment Service[1], can be easily extended to larger areas. Because of the etching process, holes are conical in shape with the wider diameter on the entry sides; this helps improving the dielectric rigidity. For the device to properly function, a good insulation between the grid electrodes is required, with no sharp edges, metallic fragments or conducting deposits in the channel; this has been obtained by careful optimization of the etching and cleaning procedures.

Upon application of a suitable difference of potential between electrodes, with the mesh inserted between two planes at symmetric potentials, the electric field in a channel of the GEM grid develops as shown in Fig. 2 (only the field lines crossing the channel have been represented). With 200 V applied, the field strength along the central field line reaches 40 kV cm^{-1}. Electrons released by ionization in the upper gas volume drift into the channels, avalanche in the high field region and leave towards the electrode in the lower volume; ions generated in the

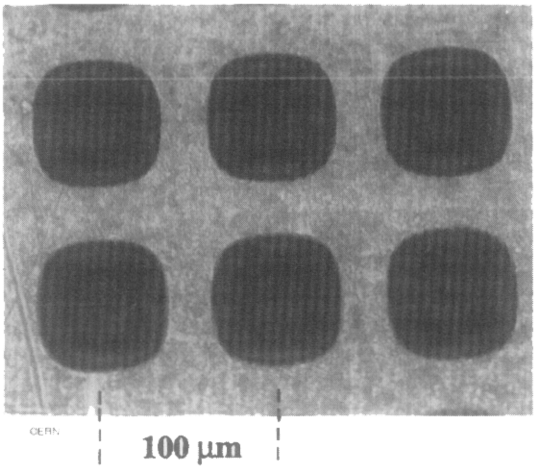

Fig. 1. Microphotography of the three-layer (metal–insulator–metal) GEM grid. The open channels diameter at the surface is 70 μm, with 100 μm distance.

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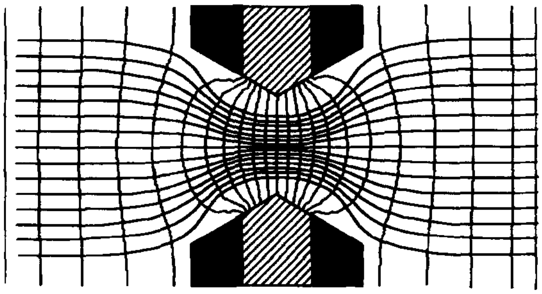

Fig. 2. Computed electric field in the multiplying channel. Only the central field lines have been plotted.

avalanche drift along the central field lines, avoiding charging up problems.

The test assembly used to demonstrate the operation of GEM is schematically shown in Fig. 3. A standard, 10 × 10 cm^2 MWPC has been modified, replacing one cathode with a thin printed circuit board holding the 5 × 5 cm^2 GEM mesh in the center; great care has been taken to avoid discharge problems at the outer edges. Above the GEM electrode, a drift plane defines the sensitive volume of the detector. Due to the focusing effect of the field, full efficiency for transfer of charge is obtained; the high density of channels reduces image distortions to values comparable to the intrinsic spread due to diffusion. For convenience, the MWPC was operated with the anode wires at positive potentials; this allows to maintain the lower electrode of GEM at ground potential, and to easily control the multiplying voltage. For ionization produced in the MWPC gaps, a regular process of collection and amplification takes place; electrons released in the upper drift region, on the contrary, can drift into and through the GEM channels and multiply, depending on potentials. Using a collimated X-ray source, the operation of the two regions can be easily disentangled. For most of this study, a 5.9 keV ^{55}Fe X-ray source has been used; to verify the rate capability, the detector has been exposed to a high intensity collimated 8 keV beam from a generator.

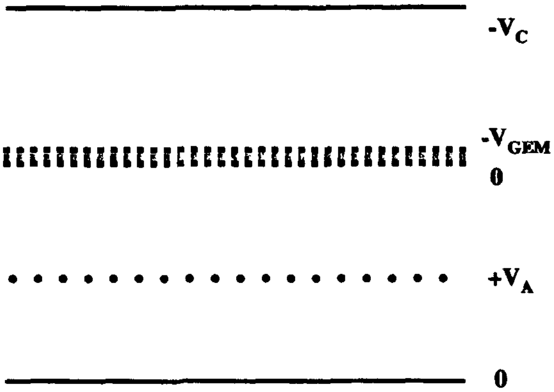

Fig. 3. Schematics of the test chamber used for the measurements. The GEM grid is installed replacing one cathode of a standard MWPC, and a drift volume is added.

In order to avoid the necessity of using excessive potentials across the GEM mesh, it is convenient to operate the detector with moderately quenched gas mixtures; a good choice is argon–dimethylether (DME) in the proportion 90–10, used for all measurements described here. The MWPC is set at a voltage providing a moderate gain ($\sim 10^4$), keeping $V_{\mathrm{GEM}} = 0$; a standard ^{55}Fe spectrum is recorded for photons converting in the MWPC volume. Keeping the upper drift electrode at fixed potential (~ -1 kV), the negative voltage on GEM is progressively increased. At $-V_{\mathrm{GEM}} \approx 50$ V, a signal begins to appear, corresponding to charge transferred from the drift region; at ~ 140 V the transferred charge equals the direct. Increasing $-V_{\mathrm{GEM}}$ further, the pre-amplified charge exceeds the direct component. Fig. 4 shows the pulse height distribution recorded at a pre-amplification factor around 6, together with the direct spectrum; the energy resolution of the detector is not affected by the pre-amplification process, implying a full efficiency of transfer of the ionization from the drift region into the channels. The first GEM mesh tested allowed pre-amplification factors close to ten to be obtained before breakdown; discharges are without any consequence to the detector.

Due to the very high dipole field inside the channels, the voltages in the drift and collection regions have only little influence on the pre-amplification characteristics, although they affect other drift properties: there is no difference in transferred charge, at a pre-amplification factor around 6, varying the drift voltage from -500 to -2000 V. This characteristics implies that the gain of the structure is very tolerant to mechanical imperfections and defects in the flatness of the grid; it can also be exploited to control independently drift velocity, diffusion and Lorentz angles according to experimental needs.

The uniformity of response of the detector has been measured by displacing the collimated source across the active area; the gain is remarkably constant, with a maximum variation of ±4% which includes possible variations in the MWPC itself.

To investigate possible gain reductions induced by charges sticking to the insulator surfaces within the channels, the detector has been exposed to increasing rates of 8 keV X-rays from a generator; the irradiated area covered about 3 mm^2. In order to be in similar conditions of charge, measurements were realized at constant total gain adjusting the MWPC potential. The preliminary results exhibit the well known space-charge dominated gain loss in the MWPC above $\sim 10^3$ counts mm^{-2} s^{-1}, identical with and without pre-amplification, implying the absence of charging up processes in the GEM mesh at these rates. Coupled to a high-rate detector, such as the MSGC, the rate capability of GEM may however be affected by charging-up of the insulator; in this case, one can envisage either to use a moderate conductivity material

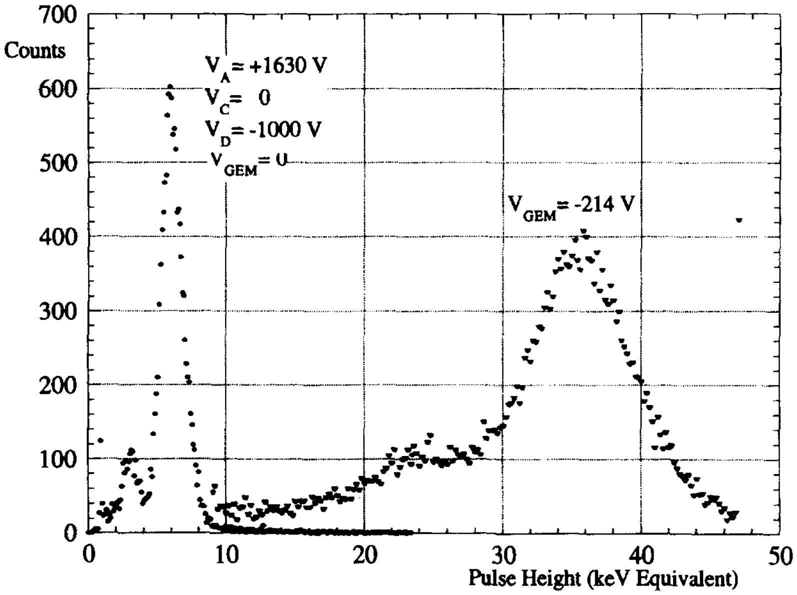

Fig. 4. ^{55}Fe pulse height recorded for X-rays directly converted in the MWPC (lower spectrum), and in the drift space with pre-amplification.

for the layer (in the range 10^{10} to 10^{13} Ω cm), or to coat the channels by vacuum or chemical vapor deposition with a thin controlled resistivity layer in the range 10^{14} to 10^{16} $\Omega/\square$, using one of the technologies developed for MSGCs [2,3].

A variety of applications can be envisaged for the GEM grid: self-supporting, the mesh can be easily incorporated in other structures, with rather coarse mechanical tolerances since the gain depends very little from the external fields. The added pre-amplification factor, even moderate, can ease the operation of any voltage-critical detector, as for example in microstrip gas chambers (MSGCs), where a serious problem of discharges has been met recently [4,5]. Operated close to their maximum gain in order to efficiently detect minimum ionizing particles, MSGCs can be irreversibly damaged by discharges initiated by heavily ionizing tracks; the effect is enhanced in presence of a high flux of radiation, and its probability depends strongly on the operating voltage [6]. The use of a GEM grid above the MSGC, with even a moderate pre-amplification factor, allow to operate the MSGC well below the critical potential for discharges. The moderate increase in the spatial extension of the detected charge, with its declustering effect, should also improve localization accuracy; the added delay, corresponding to the drift time of electrons from GEM to the MSGC plate, could be exploited for triggering.

A second application of the pre-amplification principle can be in fast RICH detectors. Aside for allowing larger gain and therefore easing single photoelectron detection, the structure can be designed to exert a high electric field on the photocathode side of the detector, thus substantially improving its quantum efficiency. Fig. 5 shows schematically an "improved" fast RICH detector with pad read-out on the MWPC cathode. The presence of the GEM mesh between the main amplification element and the photocathode also reduces the effects of photon feedback.

A more innovative use of GEM is to build a multistage gas electron multiplier, shown schematically in Fig. 6. Several composite grids, mounted within the same gas volume, and powered by a suitable resistor chain, allow to reach large gains in a succession of steps, in analogy to multigrid vacuum tubes, but with a structure substantially simpler and cheaper to manufacture for large areas; the readout can be realized with a MWPC, a MSGC or directly with a matrix of pads. The multiplier can operate in strong magnetic fields, with only small image distortions due to the Lorentz force on drifting electrons.

Intrinsically simple and exploiting well established

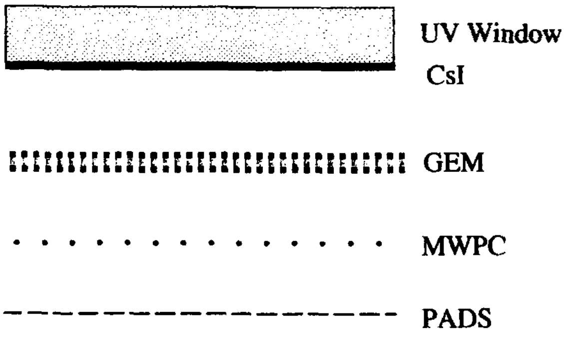

Fig. 5. A proposed fast RICH detector with pre-amplification. Providing a boost to the gain, addition of the GEM grid allows also to increase the electric field on the photocathode and to reduce photon feedback.

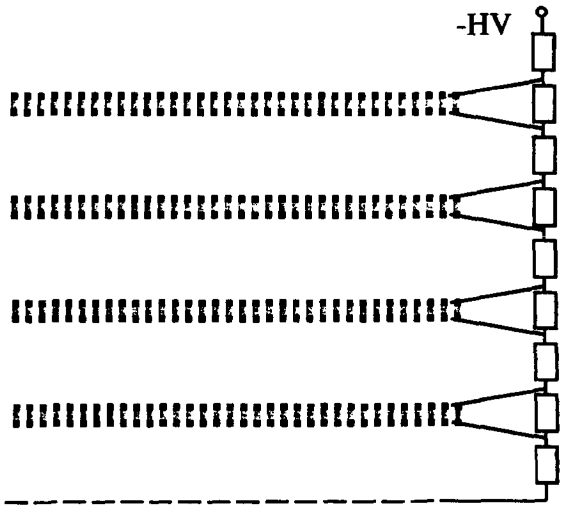

Fig. 6. A multi-grid GEM multiplier; electrons are amplified in a succession of steps. The readout can be implemented with a conventional multiwire or microstrip chamber, or directly on pad rows.

printed circuit technologies, the manufacture of the multilayer grids is nevertheless a delicate enterprise in view of the good insulation required between the two metal layers. The success of the described applications will depend on the elaboration of a suitable, reliable technique for producing the GEM grids at a low cost.

Acknowledgments

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