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Thick GEM-like hole multipliers: properties and possible applications

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Abstract

The properties of thick GEM-like (TGEM) gaseous electron multipliers, operated at 1–740 Torr are presented. They are made of a G-10 plate, perforated with millimeter-scale diameter holes. In single-multiplier elements, effective gains of about 10^4, 10^6, and 10^5 were reached at respective pressures of 1 and 10 Torr isobutane and 740 Torr Ar/5%CH_4, with pulse rise-times in the few nanosecond range. The high effective gain at atmospheric pressure was measured with a TGEM coated with a CsI photocathode. The detector was operated in single and cascaded modes. Potential applications in ion and photon detection are discussed.

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Keywords: Gem; Gaseous electron multipliers; Low-pressure avalanche multiplication; Photon detectors; Ion detectors

1. Introduction

Gas avalanche multiplication in small holes is attractive because the avalanche confinement in the hole strongly reduces secondary effects, and they provide true pixilated radiation localization. Hole-based multiplication has been the subject of numerous studies in a large variety of applications. Recently, proportional gas multiplication was demonstrated in glass channel plates (CP) [1,2]. The most attractive and extensively studied hole-multiplier is the Gas Electron Multiplier (GEM) [3], made of 50–70-μm diameter holes etched in a 50μm thick metallized Kapton foil. It operates in a large variety of gases including noble-gas mixtures, providing a gain of ~10^4 in a single element and gains exceeding 10^6 in a cascade of 3–4 elements [4,5]. The avalanche process is fast (typical rise-time of a few ns) and generally free of photon-mediated secondary effects [6]. In addition to its use for particle tracking and in TPCs, the GEM is also efficiently coupled to gaseous or solid radiation converters, resulting in a large variety of

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GEM-based radiation detectors developed for the imaging of X-rays, neutrons and UV-to-visible light [7].

The success of the GEMs and glass CPs triggered the concept of a coarser structure made by drilling millimeter-sized holes in a 2 mm thick Cu-plated G-10 printed circuit board (PCB) [2,8]. These yielded gains of 10^4 in Ar/5% isobutane and in pure Xe, and 10^3 in pure Xe when combined with a CsI photocathode (PC).

The thick GEM-like (TGEM) multiplier investigated here is a simple and robust detector, with millimeter-sized pixilation. In combination with appropriate radiation converters, it has potential applications for the detection of light, neutrons, X-rays, charged particles, etc. We describe its operation properties at very low gas pressures, in view of low-energy ion detection, and at atmospheric pressure (with a CsI photocathode), for Cherenkov UV-photon imaging.

2. Experimental setup and procedures

The TGEMs were manufactured with standard PCB technology by precise drilling and Cu etching, out of double-face Cu-clad G-10 plate, of 1.6–3.2 mm thickness. A gap of 0.1 mm was kept between the rim of the drilled hole and the edge of the etched Cu pattern (Fig. 1).

The effective gain was measured in a "current" mode with a continuous Hg(Ar) UV-lamp irradiating either a semitransparent (ST) CsI PC, placed at 8 mm above the TGEM, or a reflective (REF) PC deposited on its top face. In the first, normalization, step the photo-induced current was recorded on the TGEM with its two sides interconnected (ST PC, Fig. 2a), or on the mesh installed 6.5 mm above the TGEM (REF PC, Fig. 2b), with a drift field E_{drift} resulting in a photoelectron collection plateau. In the second step, with the ST PC we maintained the same E_{drift} field in the gap above the TGEM and recorded the current at the bottom electrode as function of the voltage difference between its both sides, keeping a slightly reversed field in the gap below the TGEM (Fig. 2c). With the REF PC we maintained $E_{drift} = 0$ for optimal electron extraction and focusing [9] and recorded the current in the same way (Fig. 2d). By dividing the current from the second measurement by that of the first one, we obtained the absolute effective gain curve; it represents the product of the true gain in the holes and the efficiency to focus the photoelectrons into the holes. The latter also varies as function of the field in the holes.

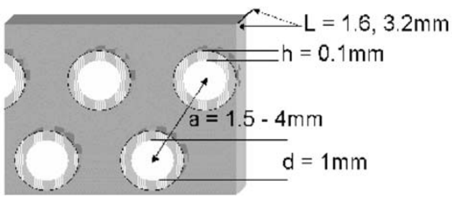

Fig. 1. Schematic view of the thick GEM-like multiplier.

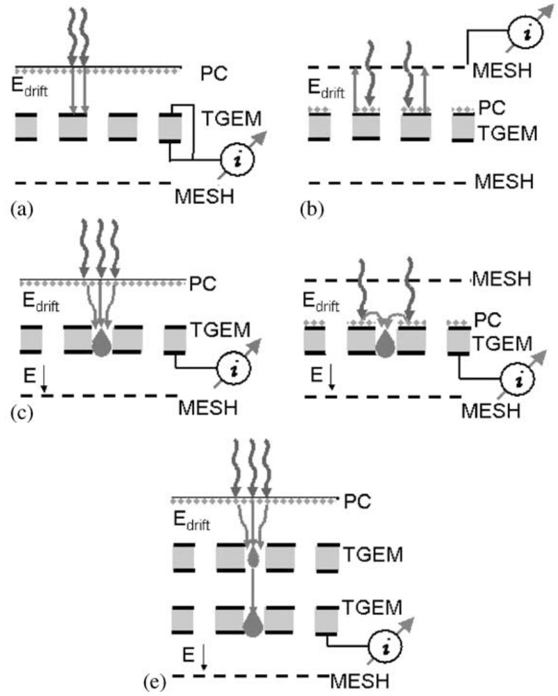

Fig. 2. Schematic setups for normalization and absolute effective-gain measurement in semitransparent (a,c), reflective (b,d) and double TGEM (a,e) modes.

Some effective-gain measurements were carried out in a "pulse" mode, with a pulsed H_2 lamp providing multi-photon bursts. Here, the charge-signal's pulse-height was recorded at the bottom

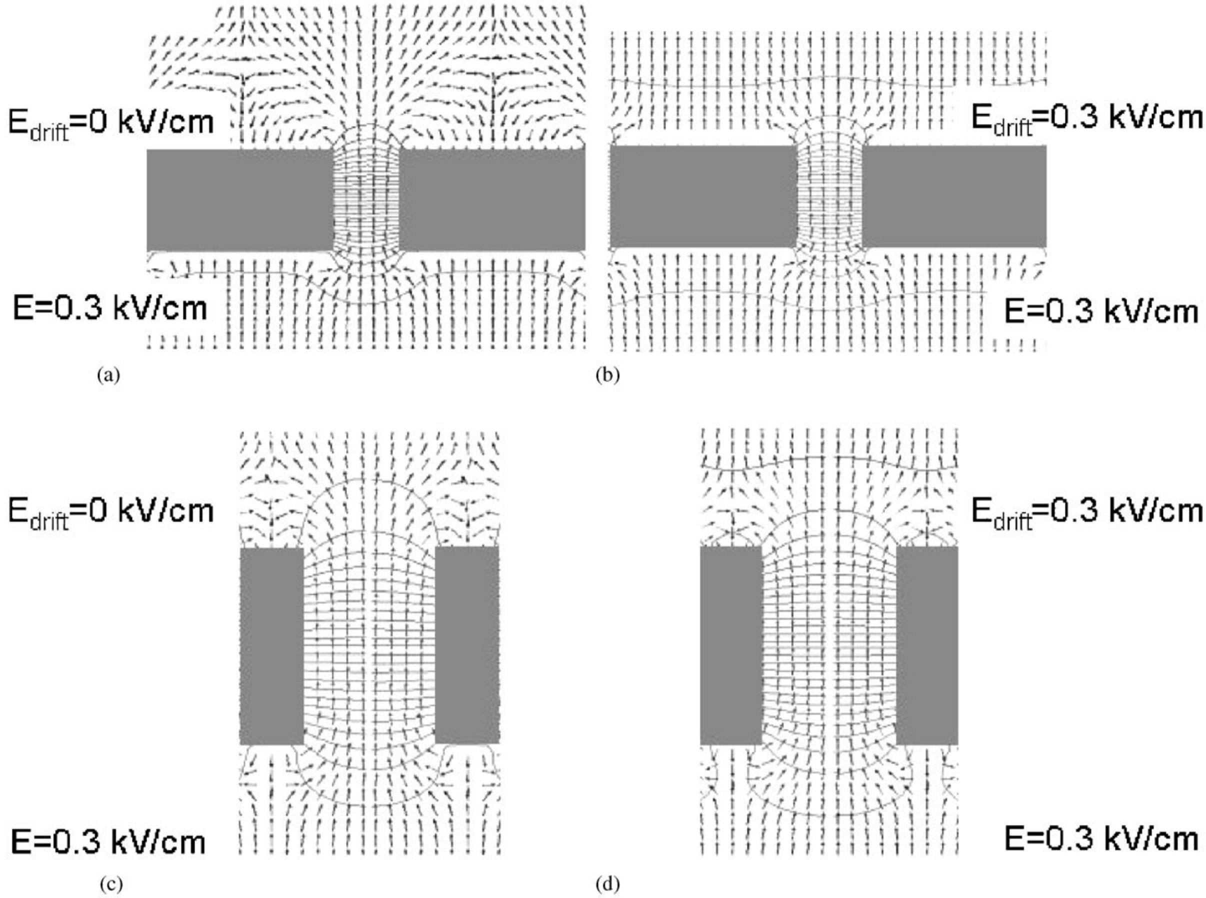

Fig. 3. Equipotential and electric-field lines calculated for TGEMs of 1.6 mm thickness with 1-mm holes. Results are shown for pitch = 4 mm (a, b) and 1.5 mm (c, d) and for $E_{drift} = 0$ and 0.3 kV/cm. Notice the different scales in the different setups.

electrode, as a function of the voltage across the TGEM; the field configurations were kept as explained above. The results of the ''pulse'' mode measurements were normalized to that of the ''current'' ones. Fast current pulses of single- and multi-photons were also recorded from the bottom electrode with a fast (1 ns rise-time) amplifier.

In a cascaded-mode operation, two TGEMs were mounted at a distance of 10 mm (Fig. 2e); currents were recorded at the bottom electrode of the second TGEM, maintaining a transfer field between the elements and a small reversed field in the gap below. This effective gain in cascaded mode involves the product of the true gains in both TGEMs, the efficiency to focus electrons into both and the efficiency to extract electrons from the first one into the gap between them. These efficiencies are a priori unknown and must still be optimized; they depend on electron diffusion and on the different electric field configurations [10].

3. Electric field calculations

The MAXWELL software package [11] was used to study the role of the TGEM's geometrical parameters and its expected performance in terms of electron transport into the holes. We can summarize the following: the field in the center of the hole does not depend on the distance

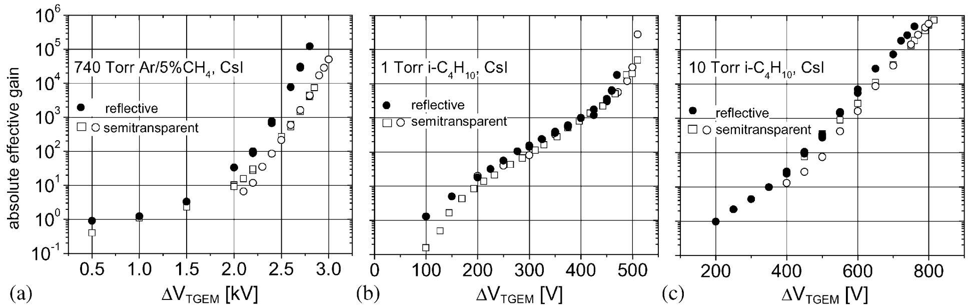

Fig. 4. Absolute effective gain measured at 740 Torr Ar/5%CH_4 (a) and at 1 (b) and 10 (c) Torr i-C_4H_{10}, in reflective mode (closed circles) and in semitransparent "current" (open squares) and "pulse" (open circles) modes.

between adjacent holes but rather on the thickness of the TGEM. The field at the center of a 1.6 mm thick TGEM, operated at atmospheric pressure under a maximum voltage difference of 3 kV, is 17 kV/cm; it is ~6 times smaller than the corresponding field in a standard GEM.

The field penetration outside the holes is also very small, of about 0.3 kV/cm at atmospheric pressure. This implies that $E_{\rm drift}$ in the gap above the TGEM has to be very carefully optimized for maximum focusing of electrons into the holes. A too-large field will transport the electrons into the metallic surface between the holes, while a too-low field implies large electron diffusion, and thus inefficient focusing. Fig. 3 shows a vectorial field-map representation, depicting the electric-field direction and strength. It is shown for 1 mm holes in 1.6 mm thick TGEM having 1.5 and 4 mm pitch, under two configurations: $E_{\rm drift}=0$ and $E_{\rm drift}=0.3$ kV/cm. For a 4 mm pitch and $E_{\rm drift}=0.3$ kV/cm (Fig. 3b), there is no efficient focusing into the holes. With $E_{\rm drift}=0$ (Fig. 3a), the direction of the field lines permits focusing of electrons originating either from the gap above the TGEM or from a converter deposited on its top electrode into the holes. However, since the field strength on the TGEM surface is practically 0 while at atmospheric-pressure operation a field $\geqslant 1$ kV/cm is required to overcome backscattering losses [12], it will not provide efficient electron extraction. For the 1.5 mm pitch, the field-line configuration is more adequate; with $E_{\rm drift}=0$, the field strength at the top TGEM electrode is >1 kV/cm at atmospheric pressure, which guarantees minimal back-scattering losses.

4. Results

All results presented in this paper refer to a 1.6 mm thick TGEM, with 1 mm holes and 1.5 mm pitch.

Fig. 4a depicts the effective gain measured at 740 Torr Ar/5% CH_4, of a single TGEM with ST and REF CsI PCs. An effective gain $\sim 10^5$ was measured with both. For the same voltage difference across the TGEM the ST mode effective gain is by a factor of 10 smaller than the REF one; it indicates a ~10 times poorer electron focusing into the holes. Moreover, in the double-TGEM mode the same effective gain was reached as with a single-TGEM under the same voltages across each TGEM, indicating considerable electron losses in the transfer between them. These observations point to a low efficiency of electron focusing from the gap into the holes, with $E_{\rm drift}$ in the range of 0.3–0.5 kV/cm in this gas mixture.

Fig. 4b depicts the effective gain measured at 1 Torr of isobutane. The total effective gain is 10^4 (at $\Delta V_{\rm TGEM}>450$ V the gain curve deviates from proportionality) and the results from the ST and the REF PC modes, measured independently, seem to overlap particularly in the higher gain range; this indicates an identical electron focusing efficiency, which is most probably high. In the double-TGEM operation mode the total effective

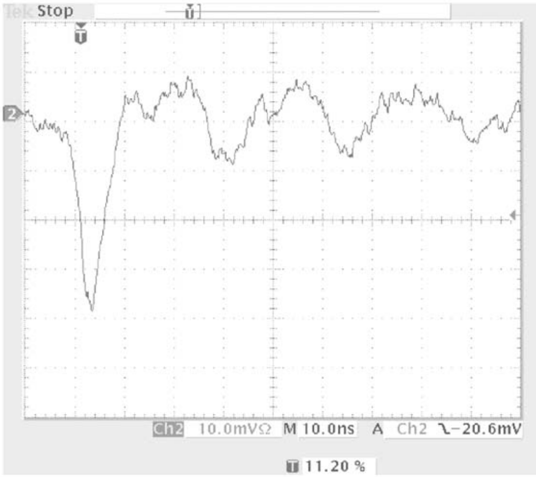

Fig. 5. A fast single-photon pulse, of 5 ns rise-time, at 10 Torr i-C_4H_{10}, gain $\sim 6 \times 10^5$. The after-pulses are due to electronic noise.

gain is also 10^4, but obtained under a much smaller voltage difference across each element; it indicates efficient electron transfer between the two multipliers. Both observations point to an efficient focusing from the gap into the holes, under $E_{drfit} = 20–25$ V/cm in this gas and pressure.

Fig. 4c depicts the data measured at 10 Torr of isobutane; the results are very similar to those at 1 Torr, with a total effective gain approaching 10^6, though there is a slight difference between the ST and REF PC modes. Similar observations and conclusions hold for the double-TGEM operation at 10 Torr, and for the electron focusing efficiency under E_{drift} of $\sim$200 V/cm in this gas and pressure.

Fast pulses recorded in a single-TGEM with single- and multi-photon bursts show rise-times of 10, 5 and 3.5 ns, at 740, 10 and 1 Torr, respectively (Fig. 5).

5. Summary and application

Thick GEM-like elements, manufactured in standard PCB technology are robust multipliers; they have astonishingly high gains: $\sim 10^5$ at atmospheric pressure and $\sim 10^4–10^6$ at 1–10 Torr. The signals are fast, with rise times in the ns range. The operation of cascaded TGEMs was demonstrated at low pressures, where the electron focusing efficiency into the holes is probably high. This operation mode is important for the suppression of secondary effects, and in particular the reduction of ion back-flow [13]. We have stressed the importance of the electron transport issue; it requires further studies for the optimization of the geometry and the electric fields.

TGEMs operated at atmospheric pressure have many potential applications. An example is in Ring Imaging Cherenkov (RICH) detectors, where photon detection over several square meters is required, generally with moderate (millimetric) localization accuracies; pad read-out with modern VLSI electronics [14,15] permits operation at gains in the $10^4–10^5$ ranges. The TGEM with a REF PC is an attractive robust solution, with very low sensitivity to background ionizing radiation [9]. Other applications could be the detection of scintillation light in large noble-gas detectors, e.g. in search for WIMPS [8] and in X-ray and neutron detectors with appropriate converters, where the gain reached in a single TGEM could be sufficient. For such applications, detector optimization is underway.

The operation at very low pressures, of 1 Torr or less, is interesting for ion detection; an example is tracking nanodosimetry, where radiation-induced ions in a very dilute gas are detected and localized to provide the ionization track structure. The dilute gas provides a factor 10^6 dimension expansion of the radiation-track image, as compared to condensed matter such as tissue, resulting in track-structure data relevant to the scale of the DNA molecule [16]. The TGEM, coupled to an appropriate ion converter, could be the basis for such an ion-imaging detector. Low-pressure TGEMs could also become adequate, economical imaging and timing detectors for heavy ions in nuclear- and atomic-physics applications.

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