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A concise review on THGEM detectors

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ABSTRACT

We briefly review the concept and properties of the THick Gaseous Electron Multiplier (THGEM); it is a robust, high-gain gaseous electron multiplier, manufactured economically by standard printed-circuit drilling and etching technology. Its operation and structure resemble that of gaseous electron multiplier's (GEM's) but with 5–20-fold expanded dimensions. The millimeter-scale hole-size results in good electron transport and in large avalanche-multiplication factors, e.g. reaching $10^7$ in double-THGEM cascaded single-photonelectron detectors. The multiplier's material, parameters and shape can be application-tailored; it can operate practically in any counting gas, including noble gases, over a pressure range spanning from 1 mbar to several bars; its operation at cryogenic (LAr) conditions was recently demonstrated. The high gain, sub-millimeter spatial resolution, high counting-rate capability, good timing properties and the possibility of industrial production capability of large-area robust detectors, pave ways towards a broad spectrum of potential applications; some are discussed here in brief.

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1. Introduction

Gaseous avalanche radiation-imaging detectors have been subject to intensive developments over the past decades. The so-called micropattern detectors, produced by different micro-lithographic techniques provide localization resolutions in the few-tens of micrometers range, approaching that of silicon trackers [1]. The most advanced operative micropattern detectors are cascaded gaseous electron multipliers (GEM) [2,3] and the Micromegas [4,5]. Within the broad family of micropattern gas detectors, the THick GEM (THGEM) is one of the most recent developments [6]; it is attracting significant attention due to its simplicity and robustness. The THGEM has a hole-structure similar to the GEM, but with about 5–20-fold expanded dimensions (Fig. 1). It is manufactured economically by mechanically drilling sub-millimeter diameter ($d$) holes, spaced by a fraction of a mm ($a$) in a thin ($t$) generally a fraction of a mm) printed-circuit board (PCB), followed by Cu-etching of the hole's rim (typically 0.1 mm). In addition to the standard etching using photolithographic masks (e.g. our THGEMs were manufactured by this process by Print Electronics Inc., Israel, www.print-e.co.il), a simpler mask-less etching technique was recently proposed and is under investigations [7]. The etched rim reduces edge discharges, resulting in over 10-fold higher gains than without a rim (Fig. 2); e.g. the “optimized GEM” [8] or “LEM” [9] have no rims.

Two or more THGEM elements can be cascaded, to provide higher gains or increase operation stability. THGEMs may be fabricated out of various PCB materials—e.g. FR-4, G-10, Kevlar, Cirlex (polyimide with low natural radioactivity [10]), Teflon, etc. Due to their mechanical robustness, THGEM-based detectors may be constructed with very large area and their implementation does not require any particular mechanical supports.

In this work we briefly review the operation principle of THGEM detectors and their properties. Details can be found in previous articles [11–15] and theses [16,17]. Some recent results on time resolution and operation in noble gases as well as potential applications are briefly discussed.

2. THGEM operation and properties

2.1. General

The THGEM’s operation principle is basically the same as that of the GEM: an electric potential is applied between the electrodes and creates a strong dipole electric field within the holes, protruding also into the adjacent volume. This particular shape...
of the field is responsible for an efficient focusing of ionization electrons into the holes and their multiplication by a gas avalanche process. The electron collection is more effective than in GEM because the THGEM’s hole-diameter is larger than the electron’s transverse diffusion range when approaching the hole.

The efficient collection and transmission of electrons offers the possibility to use several THGEM elements in cascade. This leads to higher detector gains at lower voltage bias per single THGEM element and thus to higher operation stability. This is important when the detected radiation has a large dynamic range in primary ionization density (e.g. neutrons, radioactive background, etc.).

The results of systematic studies of THGEM-based detectors, operating at atmospheric and low gas pressures, have been extensively reported in Refs. [11,12]. The role of various geometrical and operational parameters, optimal conditions for reaching full single-photoelectron detection efficiency and maximal electron transport were established. The last two prerequisites are particularly important for applications necessitating efficient photon-counting and -imaging with solid photocathodes, as in Cherenkov Ring Imaging detectors (RICH). It was found that due to the large hole size, efficient electron transport and negligible photon- and ion-feedback, the THGEM has stable operation in a large variety of gas mixtures, including noble gases. High attainable gains, $>10^4$ and $>10^6$, were reached with single photoelectrons in single- and in double-THGEM detectors, respectively, at 1 atm of Ar/5%CH$_4$ and Ar/30%CO$_2$, thus assuring good sensitivity for single-photon detection. [11,13]. The same

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**Fig. 1.** Photograph of a typical THGEM electrode; the one shown has a hole-diameter of $d = 0.4$ mm with 0.1 mm etched rim, spaced by $a = 1$ mm. The thickness is $t = 0.5$ mm.

**Fig. 2.** Maximum attainable gain vs. rim size. Detector parameters: $t = 0.4$ mm; $a = 1$ mm; $d = 0.3$ mm.

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**Fig. 3.** Schematic view of a double-THGEM soft X-ray detector; the same configuration is adequate for particle tracking and timing.

**Fig. 4.** Gain curves with 5.9 keV X-rays. (a) In single- and double-THGEM ($t = 0.8$ mm, $d = 0.6$ mm, $a = 1$ mm) in 1 bar Ar/5%CH$_4$ and (b) in double-THGEM in noble gases at 1 bar. In (a), except for Ar curve (3), measured in gas-flow mode (not purified), all other data were measured with getter-purified gases [18].
detectors yielded gains of $\times 10^3$ and $\times 10^4$ in single- and double-
THGEM arrangements, respectively, with few-hundred primary 
electrons induced by 5.9 keV X-rays in 1 atm Ar/5%CH$_4$ [14] 
(Fig. 4a). In this gas the THGEM reached counting-rate capabilities 
$>$ 1 MHz/mm$^2$ at effective gains of $\sim \times 10^4$ [11].

The localization resolution was studied with a 10 $\times$ 10cm$^2$
double-THGEM detector irradiated with 8 keV X-rays. It comprised 
two THGEM electrodes of $t = 0.4$ mm, $d = 0.5$ mm and $a = 1$ mm, 
coupled to a resistive anode; the latter broadened the induced 
signals, to match the 2 mm pitch of the X-Y delay-line readout 
electrode placed behind it. Localization resolutions of $\sim 0.7$ FWHM 
(smaller than the hole-pitch) were reached in 1 bar Ar/5%CH$_4$ at a 
gain of $10^4$; the gain variation was of 10% FWHM over the whole 
surface [14].

2.2. Noble gases and low temperatures

Gains above $10^4$ were recently measured at room temperature 
in a double-THGEM with 5.9 keV X-rays in 1 bar Ar, Kr, Xe, Ne and 
Ar/5%Xe (Fig. 4b) [18]; gains $> 10^3$ were also reached in some 
of these gases at 2–3-fold higher pressures [18,19]. The energy 
resolution dependence on various parameters (gas type, pressure, 
electrode's geometry and electric fields) was studied in detail in 
noble gases, yielding in some configurations values below 20% 
FWHM for 5.9 keV X-rays [18].

Recent studies indicated that double-THGEM detectors operated 
in two-phase liquid Ar could reach gains of $\times 10^3$ [20]. The successful operation of THGEM detectors in cryogenic conditions 
was also reported in Refs. [21,22]. Slower signal development 
compared to that in cascaded-GEM multipliers was observed in the 
two-phase operation mode; it permitted noise reduction by 
pulse-shape analysis and thus lower detection thresholds [20].

2.3. Rim effects and stability

As discussed above and shown in Fig. 2, the size of the etched 
rim around the THGEM holes, is essential for reducing signifi-
cantly discharge-occurrence probability; this permitted operation 
at higher permissible voltages and hence at higher detector gains. 
The relationship between maximum gain vs. rim-size was 
investigated with a $3 \times 3$ cm$^2$ double-THGEM, made from standard 
FR-4 PCB material, operating in Ar/5%CH$_4$, at atmospheric pressure 
(setup shown in Fig. 3). It was irradiated with a collimated 
(1 mm$^2$) $^{55}$Fe X-ray beam. The maximum attainable gain 
was defined as the one at which micro-discharges were not observed 
for at least 20 s. The maximum attainable gain increased 
practically exponentially with the rim-size (Fig. 2). This effect, 
as well as the gain stability in time, is due to a combination of 
several factors: electric field distribution outside the hole, 
charging up of the insulator, type of material, quality of hole’s 
wall-surface, the surface-quality of the Cu-edge, etc. The charging 
up of the insulator also depends on gain and counting rate. 
Preliminary results indicated that gain-stabilization with time 
occur within a few hours [15]. The matter is being thoroughly 
investigated in cooperation with CERN and INFN-Trieste within 
the CERN-RD51 collaboration.

2.4. Time resolution

The time resolution of a double-THGEM operating in 1 bar Ar/
5%CH$_4$ at room temperature was measured with UV photons 
(pulsed UV lamp) and with minimum ionizing charged particles 
(MIPs).

The detector assembled for UV-photon studies (Fig. 5) had a CsI 
photocathode, either evaporated on a transparent quartz plate 
installed at a 3 mm distance from the first THGEM (semi-
transparent photocathode), or evaporated directly onto the top 
surface of the first THGEM (reflective photocathode). Absorbers 
were used to adjust the number of incident photons per pulse. 
Both configurations yielded rather similar gain and time-resolution 
results [17].

Fig. 6 depicts the time resolution measured with a reflective 
photocathode (Fig. 5). It varied between 8 and 1 ns (RMS) for 1 to 
$100$ photoelectrons per UV-pulse. The time resolution for 1000-
photoelectron pulses was about 0.5 ns (RMS) [17].

The improved time-resolution with the number of photoelectrons results from measuring the “first-arriving photoelectron” 
among those photo-produced at different locations on the photocathode's surface or arriving at different times due to 
diffusion [17] and from improved signal-to-noise ratio.

Measurements with MIPs were done while converting radiation 
in a 3 mm drift gap (Fig. 3). The THGEM’s time-pulses were 
measured against scintillators, either with $^{106}$Ru beta-electrons or 
with cosmic rays. Both MIPs yielded similar time-resolution 
values (Fig. 7) of the order of 10 ns (RMS). The tail in the time 
distribution is due to the statistical pulse-height distribution of 
single ionization-electron pulses, affecting the trigger electronics. 
Note that we obtained, with the same setup and electronics, very 
similar tail-shape and resolution (7–8 ns RMS) were observed 

![Fig. 5. Schematic view of a double-THGEM with a reflective CsI photocathode deposited on the top one. Photoelectrons are efficiently focused into THGEM1 and multiplied in two steps.](image)

![Fig. 6. Time resolution (RMS) vs. number of photoelectrons recorded with a pulsed UV lamp in a reflective double-THGEM gaseous photomultiplier with CsI photocathode of Fig. 5.](image)
3. THGEM potential applications

The robustness, simplicity and properties of the THGEM and the possibility of industrial production capability of large-area detectors, pave ways towards a broad spectrum of potential applications. These could rely on THGEM’s single-electron sensitivity, moderate (sub-mm) localization resolution, timing in the 10 ns range, high-rate capability, low-temperature and broad pressure-range (mbar to few bar) operation.

Particle- and astroparticle-physics applications could encompass: tracking at moderate resolutions (e.g. large-area muon- or cosmic-ray detectors), sampling-elements for calorimeters, large-volume TPCs for rare events, single-photon detectors for RICH, etc.
Large-area THGEM UV-photon detectors with reflective CsI photocathodes [11,13] (Fig. 5) would have some advantages over cascaded-GEM ones [23,24]: e.g. the better electron collection and transport between cascaded elements results in a lower gain required at each single-multiplier step or, alternatively, fewer cascaded elements for an equal total gain. Like in reflective-GEM photomultipliers, a small reversed drift field above the photocathode reduces significantly the detector’s sensitivity to charged particles (Fig. 8) [23,25].

The high electric fields at the THGEM’s photocathode surface (between holes), reaching values of a few kV/cm, even at low THGEM potentials, (Fig. 9) assure good photoelectron extraction. The latter results in reasonably good effective-QE values [26] also in noble-gas mixtures (Fig. 10) [27,28].

A Resistive THGEM (RETHGEM) [28] was recently introduced, in an attempt to conceive a spark-immune multiplier. In the RETHGEM the Cu-clad (Fig. 1) is replaced by a resistive coating e.g. resistive Kapton, silk-screen-printed surface, etc. Like other detectors with resistive surfaces (e.g. RPCs) it has an improved resistance to discharges, but at the expense of lower counting-rate capability—of the order of 10–100 Hz/mm². Gains $\rangle 10^5$ were reached in different gases in double-RETHGEM coupled to a CsI photocathode [28].

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**References**