CPC(HEP & NP), 2010, **34**(1): 83–87 Chinese Physics C Vol. 34, No. 1, Jan., 2010

Experimental study on the performance of a single-THGEM gas detector*

AN Zheng-Hua (安正华)[1,2;1)] LÜ Jun-Guang(吕军光)[1] WANG Zhi-Gang(王志刚)[1,2] CAI Xiao(蔡啸)[1]
DONG Ming-Yi(董明义)[1] FANG Jian(方建)[1] HU Tao(胡涛)[1] LÜ Qi-Wen(吕绮雯)[2,3]
NING Fei-Peng(宁飞鹏)[1,3] SUN Li-Jun(孙丽君)[1] SUN Xi-Lei(孙希磊)[1,2]
WANG Xiao-Dong(王晓东)[1,3] XUE Zhen(薛镇)[1,4] YU Bo-Xiang(俞伯祥)[1]
ZHANG Ai-Wu(章爱武)[1,2] ZHOU Li(周莉)[1] ZHENG Yang-Heng(郑阳恒)[2]

[1] Institute of High Energy Physics, CAS, Beijing 100049, China
[2] Graduate University of Chinese Academy of Sciences, Beijing 100049, China
[3] Shanxi University, Taiyuan 030006, China
[4] University of Science and Technology of China, Hefei 230026, China

Abstract A kind of thick GEM-like gaseous electron multiplier (THGEM), which is mechanically an expansion of the GEM with its various dimensions being enlarged, is studied. The leak current of THGEM plates is measured. The effective gain and energy resolution of a single THGEM are studied with a source of ^{55}Fe, and the effective gain of the single THGEM versus the electric field strength in the induction region is investigated. The results show that the leak current of THGEM plates is less than 200 pA. In an atmospheric-pressure standard gas mixture, 8×10^3 effective gain and about 32% energy resolution can be reached for the single-THGEM detector.

Key words gas electron multipliers, hole multiplier, effective gain, energy resolution

PACS 29.40.-n, 29.40.Cs, 29.40.Gx

1 Introduction

Hole multipliers, because they are especially attractive, have been the subject of numerous studies and widely applied in the field of particle physics experiments. The famous and extensively studied hole multiplier is the gas electron multiplier (GEM) [1]. What we describe here is a thick GEM-like gaseous electron multiplier (THGEM) [2] which is mechanically an expansion of GEM, operating at atmospheric pressure. THGEM's structure is similar to that of GEM, but it has a geometrical dimension expansion. In comparison with a standard GEM, the spatial resolution of THGEM (sub-millimeter) is not as good as GEM's (a few tens of microns) [3], but THGEM is more robust, cheaper and can reach higher gain than GEM.

Most of the GEMs used are of a standard design: 50 μm thick kapton foil with 5 μm copper electrodes, and 70 μm holes arranged in a triangular pattern with 140 μm between centers. Generally the configuration of the micron holes of GEM is double-conical. THGEM is fabricated with a standard printed-circuit board (PCB) technique. The electrode of THGEM made by drilling millimetric holes in a 0.5–2 mm thick Cu-plated G-10 PCB around each hole chemically etched the rim by about 0.1 mm [4]. This similarity of structure and difference in the dimension scales give a similar operation principle and different experiment results in THGEM and GEM.

The THGEM operation principle is similar to that of standard GEM. Upon application of a high voltage difference across the electrodes of THGEM, a strong electric field (E_{hole}) is established within the holes. Calculating the strength of the electric field of THGEM by MAXWELL 2D [5], the E_{hole} within the hole can reach a maximum of 25 kV/cm. Electrons deposited by ionizing radiation in the drift region drift

Received 19 January 2009, Revised 10 February 2009
* Supported by National Natural Science Foundation of China (10675146, 10775151, 10775181)
1) E-mail: anzh@ihep.ac.cn

towards the THGEM under the drift field (E_D) and then are focused into the dipole field within the micron-hole. The electrons are multiplied within the hole under a strong electric field E_{hole}. In an atmospheric-pressure standard gas mixture, the effective gain can reach 10^3–10^4 for a single-THGEM element which is about 50 times larger than a single GEM's [6]. 10^6 effective gain of a double THGEM has been observed [4].

For the study on the performance of THGEM, an effective area of 50 mm×70 mm THGEM board was produced. The multiplier property and the energy resolution of single THGEM were studied with a source of ^{55}Fe 5.9 keV X-rays.

2 The structure of the THGEM electrode

The THGEM plates were designed by us and then were produced in the PCB industry [7]. FR-4 (S1141), which is a type of material commonly used for making PCBs in industry, is used for the PCB insulator, because of its good electrical quality especially in terms of flame resistance and dielectric withstanding and excellent mechanical process ability. The THGEM electrodes are made of double-sided copper-clad plates. The thickness of the insulator is 1 mm (±0.04 mm) and the variation of the plate thickness is lower than 3%. The thickness of the copper electrode is 25 μm. The insulator was first drilled with a hexagonal pattern of holes of diameter 0.3 mm and pitch 1 mm. Then the copper was etched at a 60 μm distance around the hole's rim (Fig. 1). The effective area of THGEM is 50 mm×70 mm, and there are 3500 holes on the plate.

Because it is a special new product for the PCB industry, the THGEM plate production process is immature. The created holes are classified into three groups according to the detector's operation mode.

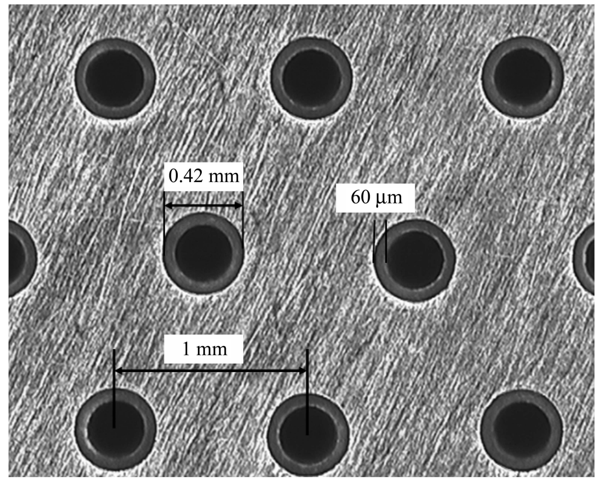

Fig. 1. A photograph of a 1 mm thick THGEM with 0.3 mm hole diameter, 1 mm pitch and 60 μm etched copper rim, preventing discharge at high potentials.

(a) Good holes: The structure of the hole is ideal (Fig. 2(a)). The electric field concentrates on the center of the hole. These holes can tolerate higher voltages and run stably.

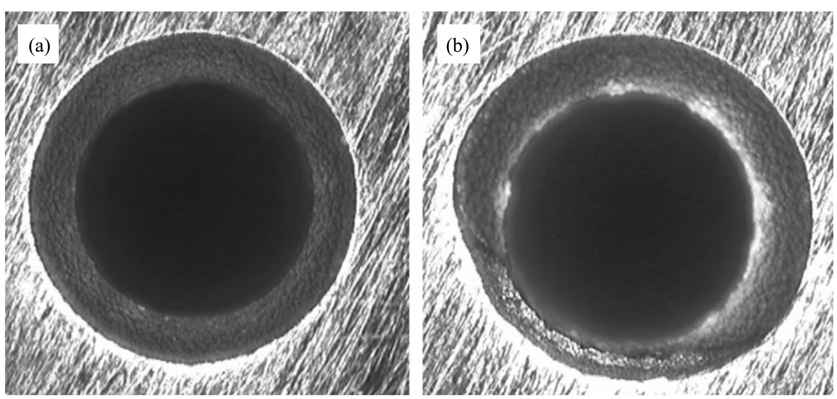

Fig. 2. (a) A photo of a typical good hole; (b) A photo of a typical bad hole.

(b) Flawed holes: Flawed holes are due to technical error. The center of the drilled hole and etched hole was not precisely centered, there is more than 10 μm displacement between the two centers. Sometimes this situation appears in all holes of the plate. To get a proper test performance, the technical error should be controlled in the production process.

(c) Bad holes: These holes are due to the etching process. Some parts of the rim around the hole are not etched at all and there are some protrusions on the rim of the etched copper. As shown in Fig. 2(b), these holes will induce discharge when high voltage is supplied. The detector will not operate properly at all. In all the area, the ratio of the bad holes is small, and this is not a serious problem for the imaging of X-rays or spacial resolution for experiments. So when bad holes are found in experiments, we deal with these holes to prevent them from discharging in operation.

Figure 3 is a schematic diagram of the single-THGEM detector. The gap of the drift region is 5 mm. The distance between the induction electrode and the THGEM plate is 3 mm. The signal was read out by an induction electrode using a standard PCB board with small pads.

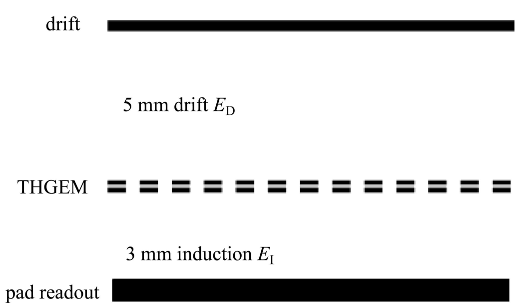

Fig. 3. Single-THGEM detector set-up.

To independently vary the electric field of different regions, individual high voltage power (CEAN N471A and N126) is supplied to every electrode. Also there is a 110 M Ohm serial resistor added to limit the eventual discharge current. The operation gas of the THGEM detector is Ar/CO_2(70:30) at atmospheric-pressure, and the style of the gas supply is flow.

3 Result and discussion

Leak current measurements of THGEM plates were obtained when high voltage was added across the THGEM electrodes by a picoammeter (KEITHLEY 6485). When studying the multiplier property of the single THGEM detector, a preamplifier (ORTEC 142AH), connected with a linear amplifier (ORTEC 570), coupled with a readout using a multichannel analyzer (ORTEC 916) was applied. The electronic chain sensitivity and linearity were calibrated for effective gain and energy resolution measurements, using a calibrated capacitor directly connected to the preamplifier input and to a precision pulse generator.

3.1 The measurement of leak current of THGEM plates

In air, with relative air humidity lower than 30% and temperature 24℃, we measured the leak current of three THGEM plates. The leak current of the THGEM plates was measured from 100 V to 3000 V at 200 V intervals. The results of the measurement are shown in Fig. 4. The leak currents of the three THGEM plates are all lower than 200 pA, when the high voltage across the THGEM electrodes is under 3 kV. That means that the insulation resistance of the three THGEM plates is larger than 15 T Ohm.

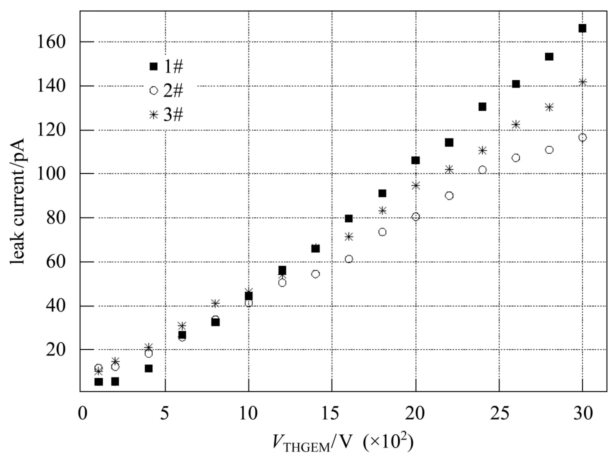

Fig. 4. The leak current of three THGEM plates.

3.2 THGEM effective gain and multiplier property

The effective gain of the single THGEM has been tested. The effective gain as a function of electric field strength of induction (E_I) has also been studied. In measurement, we use a 130 μm transparent electrode as the drift electrode and a standard PCB board with a small pad of 3 cm×3 cm area as the induction electrode.

(1) The effective gain of THGEM

Figure 5(a) shows the effective gain of the single THGEM as a function of high voltage across the THGEM electrodes (V_{THGEM}), in Ar/CO_2 (70:30) with $E_D = 2$ kV/cm and $E_I = 5$ kV/cm. The effective gain of THGEM increased with V_{THGEM} by a good exponential way. When $V_{\mathrm{THGEM}} = 2625$ V, the effective gain of the single THGEM detector can reach 8×10^3. This result is just 2 times less than the triple-GEM's gain [8].

(2) The effective gain versus induction field

Figure 5(b) shows the effective gain of the single THGEM as a function of E_I, in Ar/CO_2 (70:30) with $E_D = 1.5$ kV/cm and $V_{\mathrm{THGEM}} = 2550$ V. The result shows that the effective gain of THGEM can reach a saturation state and the avalanched electrons are almost fully collected by the induction electrode, when the electric field in the transfer region is over 4.5 kV/cm.

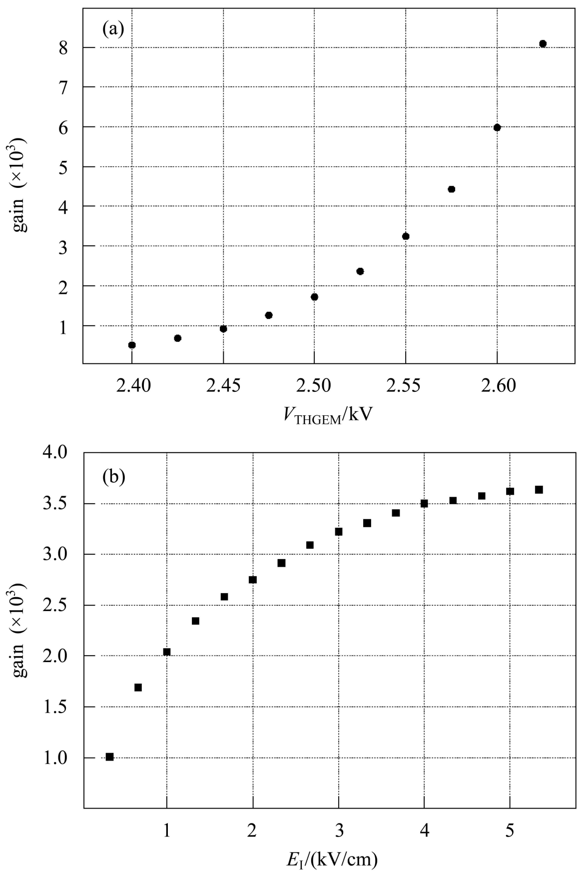

Fig. 5. (a) Effective gain of the single-THGEM multiplier, measured in Ar/CO_2 (70:30) with $E_{\rm D}$ = 2 kV/cm and $E_{\rm I}$ = 5 kV/cm; (b) Effective gain of single-THGEM as a function of $E_{\rm I}$, in Ar/CO_2 (70:30) with $E_{\rm D}$ = 1.5 kV/cm and $V_{\rm THGEM}$ = 2550 V.

3.3 X-ray energy resolution of the THGEM detector

The energy resolution of the THGEM detector was measured with a ^{55}Fe 5.9 keV X-ray. Fig. 6(a) shows the energy spectrum of ^{55}Fe. In measurement, we used a 20 μm thick aluminum polyester foil as the drift electrode and a standard PCB board with a pad of 7 cm×8 cm area as the induction electrode. A drift gas gap of 5 mm was added in front of the THGEM electrode, with a drift field of $E_{\rm d}$ = 0.33 kV/cm, $V_{\rm THGEM}$ = 2525 V and $E_{\rm I}$ = 4 kV/cm. The detector was operated at an effective gain of 1.2×10^3. Pulses were recorded via a charge-sensitive preamplifier (ORTEC 142AH) and a linear amplifier (ORTEC 570), on a multi-channel analyzer (ORTEC 916). The ^{55}Fe source was collimated by a 2 mm thick lead with a 2 mm diameter hole. The result shows that the escape peak of Ar is obvious, and the energy resolution of the ^{55}Fe 5.9 keV X-ray full energy photo-electron peak is ∼31% FWHM.

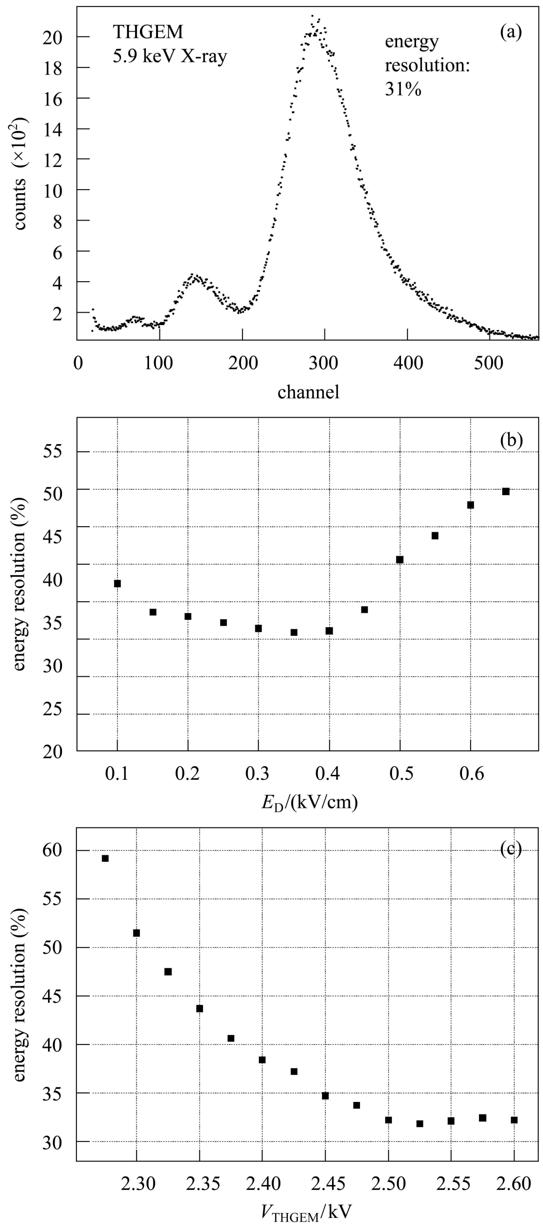

Fig. 6. (a) An energy spectrum with a 5.9 keV ^{55}Fe X-ray in a single-THGEM, Ar/CO_2 (70:30) mixture, effective gain 1.2×10^3; (b) Energy resolution as a function of $E_{\rm D}$, in Ar/CO_2 (70:30) mixture with $E_{\rm I}$ = 4 kV/cm and $V_{\rm THGEM}$ = 2535 V; (c) Energy resolution as a function of $V_{\rm THGEM}$, in Ar/CO_2 (70:30) mixture with $E_{\rm D}$ = 0.33 kV/cm and $E_{\rm I}$ = 4 kV/cm.

Figure 6(b) presents the energy resolution as a function of $E_{\rm D}$. With the variation of $E_{\rm D}$, the energy resolution changes dramatically. When $E_{\rm D}$ =

0.35 kV/cm the best energy resolution of the single THGEM detector can be obtained. The reason for this is that the pitch between two holes is large (1 mm) compared with the diameter of the hole (0.3 mm), and the drift direction of ionized electrons will be changed by a strong E_{D}. That will mean that the electrons cannot be focused into the holes of THGEM by the dipole field of the hole. So the energy resolution becomes worse. Fig. 6(c) shows the energy resolution as a function of V_{THGEM}. With the increase of V_{THGEM}, the effective gain of the THGEM increases and the energy resolution of THGEM becomes better. When V_{THGEM} is over 2.5 kV, the energy resolution is ~32% and it is stable.

The reason for unsatisfactory energy resolution may be caused by two reasons: 1. The effective gain of the single THGEM is not large enough and the ratio of signal to noise is small. This will make the energy resolution worse. 2. The immature production process of the THGEM plate leads to the non-uniformity of the electric field of THGEM holes. The difference of the electric field of the holes makes the energy resolution worse.

4 Conclusion

THGEM is a robust and stable gaseous detector. Due to the large hole size, the THGEM detector has a lower requirement for environment of operation and has little chance to discharge, even if there is a little dust on it. The leak current of THGEM is small, generally lower than 200 pA when the high voltage across the THGEM electrodes is under 3.0 kV. This means the insulation resistance of THGEM is larger than 15 T Ohm. An effective gain of 10^3–10^4 and fast pulses with rise time in the ten nanosecond scale are reached in the single-THGEM detector. Higher gains of single and double THGEM have been observed [4], after optimization of the insulator width of the rim and other geometrical dimensions. Because the THEGM electrodes can be produced by an economic and simple method, the THGEM multiplier-detector will have wide application in the field of particle physics experiments for large area sub-millimeter localization resolution at atmospheric pressure. If coupled to a neutron converter or other gaseous or solid radiation converters (e.g. a photocathode), the THGEM detectors will have more fields of application.

From the results of the experiment, the THGEM detector has the following properties:

(1) The voltage across the THGEM electrodes is much higher than GEM. In an atmospheric pressure standard gas mixture, the voltage of the single THGEM with 1 mm thickness is 2.2 kV for the avalanche process. For a double-THGEM multiplier, the total high voltages will go up to more than 9 kV. This requires a high quality, high voltage system.

(2) The effective gain of THGEM as a function of E_{I} is simple. The detector can work at a strong E_{I}.

(3) The energy resolution of THGEM is dramatically influenced by E_{D}. Too strong an E_{D} will make the energy resolution worse. In order to get a good energy resolution, a suitable E_{D} is determined by the pitch of the THGEM holes and the strength of the dipole field of the holes. The condition of getting a good energy resolution is that all the ionized electrons are focused into the hole to avalanche.

(4) When THGEM is operated in high gain mode, discharge eventually occurs. But generally small number of discharges will not damage the THGEM electrode plate. Investigation of the long-term gain stability of THGEM needs more time.

In summary, the THGEM is a new gaseous detector with wide potential applications in many fields. The optimization of THGEM needs a systematic study. The spatial resolution of THGEM as a function of size and pitch of the hole is the subject of our subsequent research. The rim width versus effective gain is also an important subject.

We wish to express our thanks to Prof. Wang Pei-Liang for the useful information about calibration as well as to Prof. Heng Yue-Kun and Dong Jing for their suggestions and material.

References

1 Sauli F. Nucl. Instrum. Methods A, 1997, **386**: 531–534
2 Chechik R, Breskin A, Shalem C. Nucl. Instrum. Methods A, 2004, **535**: 303–308
3 Ledermann B, Kaminski J, Kappler S et al. Nucl. Instrum. Methods A, 2007, **581**: 232–235
4 Shalem C, Chechik R, Breskin A et al. Nucl. Instrum. Methods A, 2006, **558**: 475–489
5 MAXWELL 2D Student Version, ANSOFT Co. Pittsburg PA, USA
6 Bachmann S, Bressan A, Capeans M et al. Nucl. Instrum. Methods A, 2002, **479**: 294–308
7 Shenzhen King Brother PCB Technology Co., Shenzhen, China
8 DONG Jing, XIE YI-Gang et al. HEP & NP, 2007, **31**(8): 664–668 (in Chinese)