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Experimental study on the performance of a THGEM detector for X-rays

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HIGHLIGHTS

- Introducing a new structure THGEM detector.
- Cascading three domestically produced THGEMs for gain increase and stable operation.
- Characterization of the X-ray detector working in Ar/CO_2 mixtures at different pressures.
- High gain accessibility of 10^6 for Ar/CO_2 (80/20) mixture.

ABSTRACT

By expanding the applications of GEM detectors, a newer pattern of such detectors was introduced in 2004, named THGEM detectors. In this work, a sample of an X-ray detector was designed and constructed using 2 cm × 2 cm THGEMs domestically produced with a thickness of 250 μm, a hole diameter of 300 μm and a pitch of 500 μm, for the first time. The triple THGEM detector working in Ar/CO_2 gas mixture was characterized. Influence of gas pressure and gas mixture on gain of the detector was investigated. Results show the detector operated in a stable mode with no discharges. The gain of the detector increased with high voltage across the THGEM electrodes exponentially. This verified the performance of a detector as a proportional counter. Also, the detector's gain is maximum at Ar/CO_2 (80/20) gas mixture and voltage of 700 V applied to each multiplier. The detector is promising for localization applications such as particle physics experiments.

KEYWORDS
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1 Introduction

Recent years have seen significant advancements in micropattern gaseous detectors (MPGDs). The most operative MPGDs are Gaseous Electron Multipliers (GEMs) (Sauli, 2016). In a GEM, a structure for charge amplification introduced in 1997, the avalanche occurs in the holes patterned in a metal-clad insulator plate (Sauli, 1997). In 2017, detailed performance study of a 10 × 10 cm^2 triple GEM detector operated using Ar and CO_2 gas mixtures in proportions of 70/30 and 90/10 had been made. In this work, the uniformity of the detector had been investigated by dividing the detector in 7 × 7 zones and measuring the gain and energy resolution at the centre of each zone (Patra et al., 2017). In 2020, the performance of GEM detectors operated in gas recirculating systems have been studied at the CERN Gamma Irradiation Facility (Corbetta et al., 2020). Also in this year, charging-up and performance of the triple GEM detector for plasma radiation monitoring was investigated (Chernyshova et al., 2020).

Although the extensive applications of a GEM detector, its fabrication is so complex. Thus, a developed form of a GEM detector called a THGEM detector was established in 2004 (Chechik et al., 2004). THGEM's structure is similar to that of GEM, but it has a geometrical dimension expansion (Titov, 2007). In comparison with a standard GEM, THGEM is more robust, cheaper and can reach higher gain than GEM. It is manufactured by mechanically drilling sub-millimeter diameter holes in a thin printed circuit board (PCB) (Alfonsi et al., 2004). THGEM operation principle is similar to that of standard GEM. Upon application of a suitable difference of potential between electrodes, with the multiplier inserted between two planes, a high electric field develops in each hole. Electrons released by ionization in the upper gas volume drift into the hole, avalanche in the high field and

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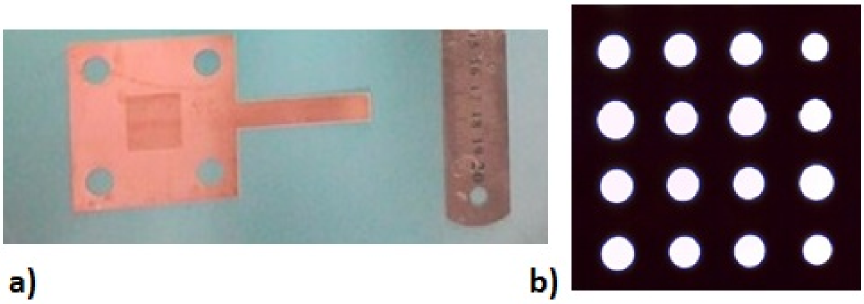

Figure 1: a) A fabricated THGEM b) a microscopic photograph of a THGEM holes.

leave towards the electrode in the lower gas volume. A sub-millimeter hole diameter is larger than electron diffusion in most gases, with consequently favorable electron transport into and out of the holes (Cortesi et al., 2007).

Since THGEM introduction in 2004 (Chechik et al., 2004), it has been extensively studied over a broad range of gases and pressures; details are found in reviews (Breskin et al., 2009). Also, properties of the THGEMs such as localization capability, gain homogeneity and long-term stability was investigated in 2006 (Cortesi et al., 2007). Some results on time resolution and operation in noble gases as well as potential applications were discussed in 2008 (Yang et al., 2015). Energy resolution of single THGEM were studied with an effective area of 50 mm × 70 mm in 2010 (Breskin et al., 2010). Previous samples of THGEMs made in Iran with a thickness of 0.35 mm, diameter of the holes of 0.5 mm and a pitch of 1 mm used for alpha radiation detection (Najarzadeh et al., 2023) and neutron detection (Hashemi and Negarestani, 2019). It is obvious that reducing the diameter of the holes and pitch of a THGEM improves gain and resolution of the detector. In this paper, we designed and constructed a triple THGEM gas detector using 2 cm × 2 cm THGEMs domestically produced with a thickness of 250 μm, a hole diameter of 300 μm and a pitch of 500 μm for the first time. The fabricated THGEMs was tested, at first. Gain of the detector was evaluated by proper voltage choice and filling gas mixture and gas pressure effect was surveyed.

2 Experimental

Fabrication of a multiplier is done with different methods such as photolithography (Everaerts, 2006), laser beam (Tamagawa et al., 2006) and ion micromachining (Daniel and Moore, 1999). In this research, the THGEMs were designed using Designer altium software and then were produced in the PCB industry. The method applied for a PCB was used due to the availabe facilities, which is in fact CNC drilling. The insulator with a thickness of 250 μm was drilled with a pattern of holes of diameters 300 μm and a pitch of 500 μm. The total area of THGEMs was 6 cm × 6 cm, the active area was 2 cm × 2 cm and there were 1600 holes in a 40 × 40 matrix on the electrode. This configuration was made for the first time in the country demonstrated in Fig. 1-a. A microscopic image of a THGEM is shown in Fig. 1-b.

Figure 2-a is a schematic setup of a triple THGEM detector. The gap of drift region was 4 mm. The distance between the THGEMs was 2 mm. The triple THGEM setup, the multiplier assembly (Fig. 2-b), was located in a gaseous vessel, shown in Fig. 3 and fed by three power supplies shown in Fig. 4. The operation gas of the THGEM detector is Ar/CO$_2$ at atmospheric pressure. The signal

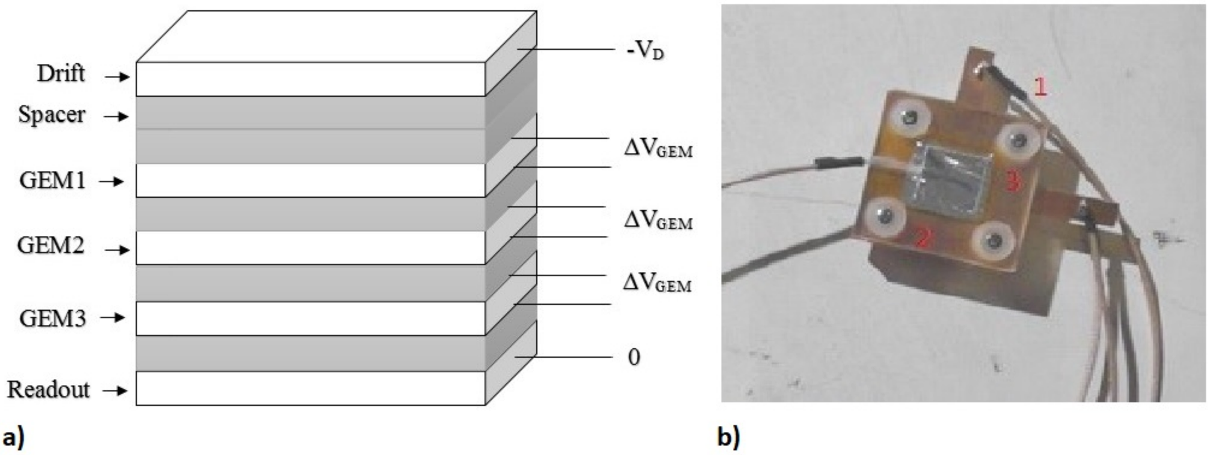

Figure 2: a) Triple THGEM detector scheme b) Top view of the multiplier assembly: 1) Appling voltage to each plate 2) Drift plate 3) Teflon screw for aligning plates on each other.

was read out by an induction electrode which is the same as a multiplier layer without the active area.

The collected charge on the induction layer read out with an ORTEC 142 preamplifier followed by an ORTEC 570 amplifier and an ORTEC multi-channel analyzer.

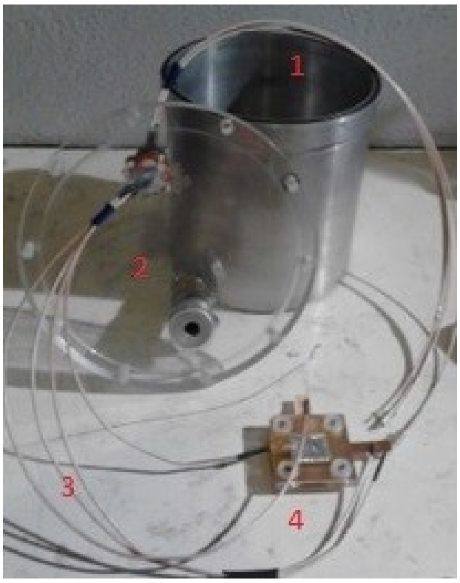

Figure 3: 1) The gaseous vessel 2) Cap of the gaseous vessel with a feed through and a gauge pressure connection 3) Bias connections 4) The multiplier assembly.

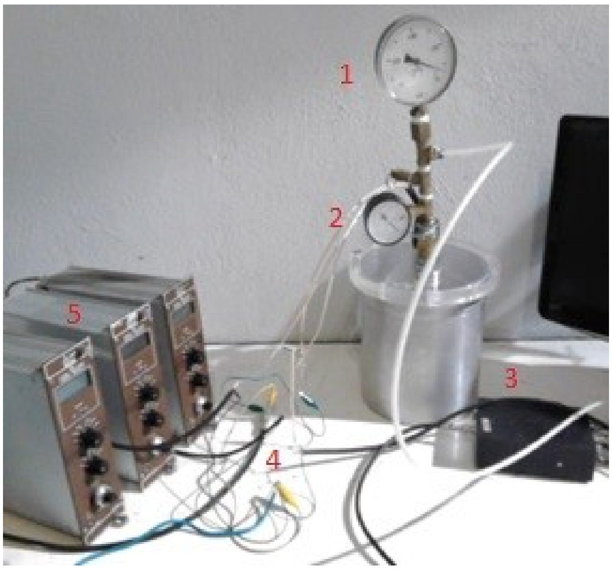

Figure 4: 1) Pressure gauge 2) Vacuum gauge 3) Preamplifier 4) Bias connections 5) Power supplies.

3 Results and discussion

At first, several THGEM foils were tested before use. First of all, they were checked by a microscope whether the designed sketch of the holes was applied completely or not as any defect influences the detector performance. Also, the diameter of the holes was measured by the microscope software. The samples with uniform hole diameter distribution cause the gain of the detector be uniform on the active area. After that, the samples were checked if there is an electric contact between the electrodes. The samples which were not meet the criteria, were discarded as any defects during fabrication procedure can cause the electric discharge. Then, the electric discharge probability was surveyed by voltage gradually increase. The fabricated samples did not damage up to 700 V. The foils which showed the best performance were chosen for the next tests, below.

The detector was tested using a Fe-55 X-ray source (activity 1 mCi) which provides 5.9 keV X-rays. The source was positioned in such a way that a collimated beam perpendicularly entered the upper drift region. The gain of the detector as a function of applied voltage to each THGEM was studied. Although the gain of the detector can be increased using a cascade, discharge probability is decreased as each THGEM works at lower and safer voltage. Therefore, three THGEMs were cascaded in this research.

Figure 5 shows the gain of the detector as a function of high voltage across the THGEM electrodes in Ar/CO_2 (70/30) with drift field of 2 kV.cm^{-1} and induction field of 1 kV.cm^{-1}. The gases were supplied in a high purity percent, 99.999% for argon and 99.99% for CO_2. The gain of the detector increased with voltage of THGEM in a good exponential way. This verified the performance of the detector as a proportional counter. The detector can provide an effective gain of 10^5 in Ar/CO_2 (70/30). The results are in good agreement with the results reported by Bencivenni (Bencivenni et al., 2002). Nevertheless, the operation was stable with no occasional discharges.

In order to study the characteristics of the detector, its performance was investigated in the different gas mixtures. Figure 6 shows the gain of the detector in the different Ar/CO_2 mixtures. As it can be seen, gain increases with voltage. For Ar/CO_2 (80/20), the gain reached to 10^6 at voltage of 700V. The working voltage was lower to give the same gain for the gas mixture Ar/CO_2 (80/20) in comparison with Ar/CO_2 (70/30). The multiplication factor or gain of the detector is given by $\exp(\alpha x)$, where α is first Townsend coefficient, the number of ionizing collisions per cm. The first Townsend coefficient which depends on many parameters such as nature of the gas, field and pressure, have been measured for a wide variety of gases and mixtures reported elsewhere such as Ref (Sharma and Sauli, 1993). Dependence of the first Townsend coefficient to the gas mixture verifies the observed gain variations. Figure 7 shows the gain of the detector in Ar/CO_2 (80/20) for different gas pressures. Maximum gain at voltage of 700 V and pressure of 0.5 bar obtained 10^6. As expected, the gain decreased by pressure increase. Variations of the first Townsend coefficient with pressure verify the gain reduction by pressure increase observed in this research. The results correspond well with the results reported by Alon (Alon et al., 2008).

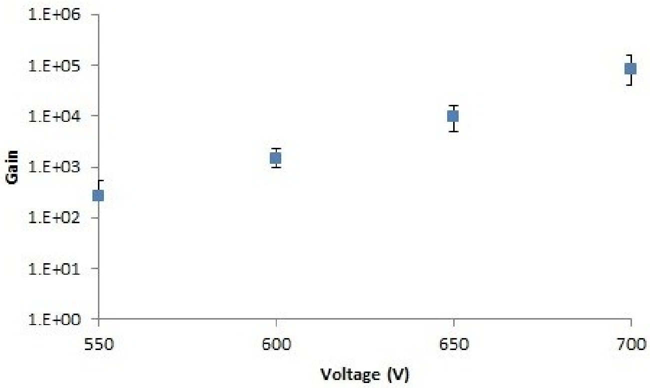

Figure 5: Variation of gain as a function of voltage.

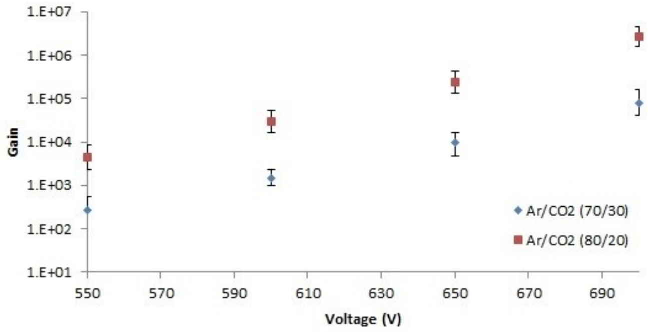

Figure 6: Gain of the detector in different gas mixtures.

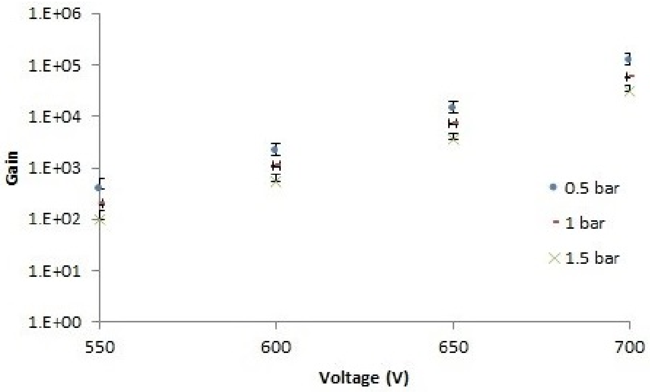

Figure 7: Gain of the detector at various pressures.

4 Conclusions

In this paper, a new type of X-ray detector based on domestically produced THGEMs is introduced and a preliminary experimental study is presented, including the performance of the triple THGEM detector working in Ar/CO_2 mixtures at different pressures. An effective gain of 10^6 was reached for Ar/CO_2 (80/20) mixture. THGEMs produced by an economic simple method operated well. Gain variation of the detector for specific drift and induction fields is being investigated. The detector is promising for particle physics experiments. If coupled to a neutron converter or a photocathode, the detector will have more fields of application.

Conflict of Interest

The authors declare no potential conflict of interest regarding the publication of this work.

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