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Discharge probability studies with a single THGEM setup

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Abstract. In Gas Electron Multiplier- and Thick Gas Electron Multipliers-based detectors the discharge stability constrains the safe operating limits in terms of achieved gain and signal amplification. Thus, this is an important optimization parameter for the overall performance of these detectors. The discharge probability has been determined for THGEMs in Ar- and Ne-based gas mixtures as a function of gain. A comparison with GEANT4 simulations allows to extract the critical charge density leading to the formation of a spark in a THGEM hole. Preliminary results of our research show that discharges are triggered by a critical charge of 2.5×10^6 and 7.0×10^6 electrons per THGEM hole in Ar–CO_2 (90–10) and Ne–CO_2 (90–10), respectively.

1. Introduction

Thick Gas Electron Multipliers (THGEMs) [1] are of similar design as GEMs [2] but with expanded dimensions increasing their robustness. During operation of such detectors the exposure to high radiation fluxes or the release of a large amount of charge in the detector volume can lead to a breakdown in the gas. These sparks occur after a some amount of charge has accumulated inside a GEM hole and modified the electric fields accordingly so that a streamer can form [3]. From previous studies in parallel-plate counters it is known that a breakdown occurs when the number of charges in an avalanche exceeds 10^8, which is the so-called Raether limit [4]. Subsequently, the breakdown limit of micro-pattern gaseous detectors is of the order of 10^7 electron–ion pairs [5]. In recent studies the critical charge limit in GEMs was precisely measured and depending on the gas mixture lies within a range of $4–7\times10^6$ electrons per GEM hole [6].
In this study we intend to determine these critical charge limits for a THGEM in different gas mixtures by irradiating a single-THGEM detector with alpha particles. To be independent from effects such as the presence of transfer fields or charge sharing and spreading between foils no transfer and induction field and just the simplest configuration, a single THGEM setup, is used.
This work is structured as follows. Section 2 introduces the experimental setup. Section 3 describes the simulation framework and the corresponding analysis methods which allow to extract the values of the critical charge density. The measurements and the preliminary results are presented in Section 4. Section 5 summarises the findings and gives an outlook on the future of this study.

2. Experimental setup

A dedicated detector setup was built to study the stability of single THGEM foils against electrical discharges. Figure 1 shows a view of the experimental setup.

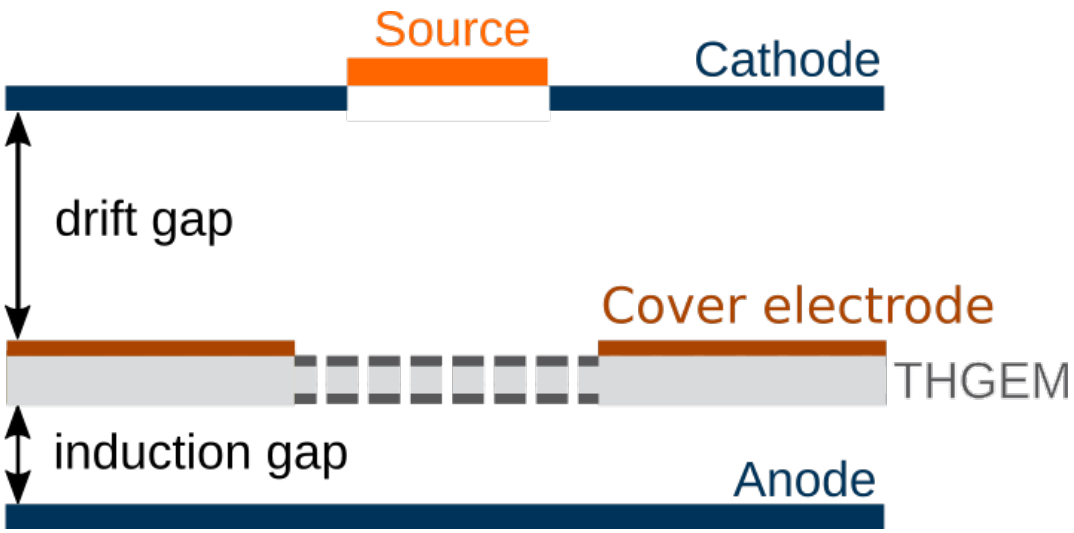

Figure 1. Schematic of the detector. A single THGEM is mounted between a drift electrode and a readout anode. The THGEM bottom electrode is read out by a pico–amperemeter.

The detector vessel contains a 10×10 cm^2 PCB with a 3×3 cm^2 active THGEM area in the middle mounted with a readout anode below and a mesh cathode above the THGEM (Fig. 2). Both cathode and anode are made of a 1.5 mm thick PCB coated with copper on one side. The THGEM is a 400 µm PCB covered on both sides with a copper layer, perforated with 400 µm diameter holes at a pitch of 800 µm. A 20 µm wide copperless rim is etched around the holes. The distance between the cathode and the THGEM (drift gap) is 35.5 mm. The distance between the THGEM and the anode (induction gap) is set to 2 mm throughout all measurements. To mitigate charge-up effects a cover electrode is installed on top of the non-active PCB area.

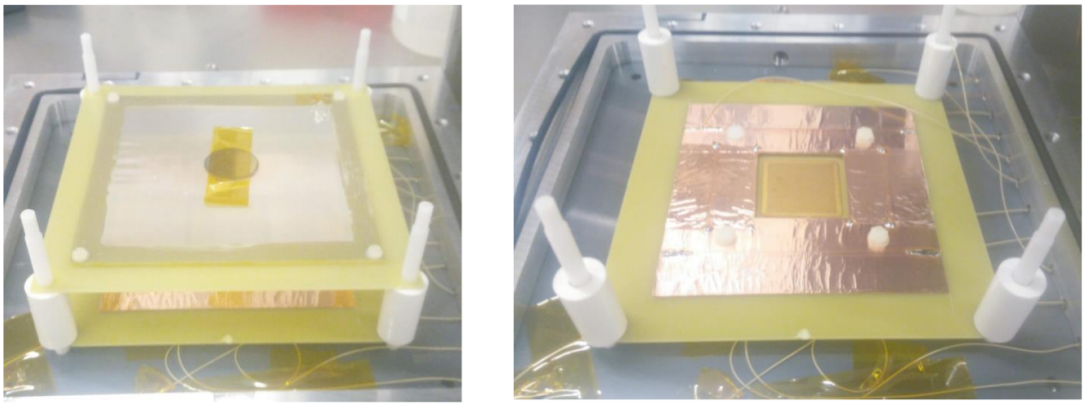

Figure 2. Photos of the detector setup with the 3×3 cm^2 THGEM.

The detector is operated with a drift field (E_{drift}), defined by the potentials at cathode and THGEM top electrode, of 400 V/cm and with no induction field. The potential applied to the cover electrode is 100 V higher then the THGEM top potential to match the drift field value. The potentials are applied via a high voltage power supply with independent channels.
The THGEM bottom electrode is readout via a pico–amperemeter. In addition, the anode is connected via inductive coupling to an oscilloscope where discharge signals can be recorded. To induce discharges a ^{239}Pu+^{241}Am+^{244}Cm α-emitter [7] is mounted on top of the cathode. The rate R of

the alpha source is ~ 30 Hz.
Two different gas mixtures are used in this study: Ar–CO_2 (90–10) and Ne–CO_2 (90–10). The oxygen and water concentrations are constantly monitored and it is ensured that the oxygen level is below 20 ppm and the water contamination is on the ppm level. At the start of measurements the current offsets of all channels are measured and taken into account for all future current measurements. Then the primary ionisation current, created by the ionisation in the drift volume, is determined at a drift field of 400 V/cm by reading out the THGEM top electrode while the anode and the THGEM bottom electrode are grounded. To control charge up effects on the current readings this measurements lasts about half an hour.
As there is no induction field present the extraction to the gap below the THGEM can be assumed to be zero. With a drift field of 400 V/cm a collection efficiency of 100% can be assumed. The absolute gain of the THGEM is determined as ratio of the amplification current measured at the THGEM bottom electrode to the primary ionisation current.
In order to avoid major corrections to the high-rate measurements, measurements do not exceed a discharge rate of 1 Hz. The discharge probability P is defined as the ratio of the discharge rate to the alpha source rate:

$$P = \frac{N}{tR} \tag{1}$$

where N is the number of discharges.

3. Simulations

The simulations follow the same method that has been used in a previous work [6]. A realistic geometric replica of the detector setup described in Section 2 is used in the simulations. The energy deposition of the alpha particles in the active medium is simulated in GEANT4 (4.10.2.p02) [8]. The particle transport in GEANT4 is performed stepwise with interactions taking place after each step. The distance between the steps is randomly sampled from the mean free path of the particle which is computed by taking into account the cross sections of physics processes summarised in the G4EmLivermorePhysics physicslist [9].
A particle gun on the cathode randomly emits alpha particles in the drift volume. The emitted alpha particles adhere to the specifications of the mixed alpha source used in the experimental setup. The field in the drift gap is included in the simulation. The exact position and energy deposition of a each hit in GEANT4 is recorded and used in further analysis. About 100 million events for each gas are simulated and analysed which is sufficient to be able to compare the simulation with the experimental data. The energy deposited by each alpha particle E_{dep} can be converted to the number of ionisation electrons n_{e} by

$$n_{\mathrm{e}} = \frac{E_{\mathrm{dep}}}{W_{\mathrm{i}}} \tag{2}$$

with W_{i} being the effective ionisation energy of the specific gas mixture (see Table 1). The integration time t_{int} is introduced to the simulation model which defines the maximum distance for charges to still be taken into account for the accumulation in a single THGEM hole. All electrons within

$$d_{\mathrm{int}} = v_{\mathrm{drift}} \cdot t \tag{3}$$

above the THGEM are then projected to the THGEM plane. The longitudinal and transverse diffusion are considered by smearing the width of the electron cloud with a Gaussian distribution according the values listed in Table 1. The drifted electrons are then sorted in a honeycomb-like grid with each honeycomb corresponding to one THGEM hole plus its surrounding area. Following the assumption of 100% collection efficiency all electrons reaching the THGEM plane are taken into account. The charges inside single THGEM holes are then multiplied by the multiplication factor of the THGEM. Following simple assumptions a discharge occurs if the accumulated charge inside a single THGEM

Gas	v_{drift} [cm µs^{-1}]	D_{L} [$\sqrt{cm}$]	D_{T}[$\sqrt{cm}$]	W_{i} [eV]
Ar-CO_2 (90-10)	3.25	0.0244	0.0268	28.1
Ne-CO_2 (90-10)	2.66	0.0219	0.0223	38.1

Table 1. Table of the properties of gas mixtures used in this study. The electron drift velocity and diffusion coefficients are evaluated at Normal Pressure and Temperature (NTP) conditions at a nominal electric field of 400 V/cm in the absence of a magnetic field.

Gas	GEM Q_{crit} [x10^6]	THGEM Q_{crit} [x10^6]
Ar–CO_2 (90–10)	4.7 ± 0.6	2.5
Ne–CO_2 (90–10)	7.3 ± 0.9	7.0

Table 2. Values of the critical charge Q_{crit} for different gas mixtures for GEMs [6] and THGEMs. The integration time t_{int} is 25 ns for Ar–CO_2 (90–10) in case of THGEMs and 30 ns in case of GEMs. For Ne–CO_2 (90–10) a t_{int} of 18 ns and for THGEMs and 50 ns for GEMs was used.

hole exceeds the critical charge threshold Q_{crit}. The final discharge probability is defined as the number of events in which the accumulated charges in a single THGEM hole exceed Q_{crit} and is normalised to the number of simulated events and the THGEM multiplication factor. In order to compare the simulated outcomes with the experimental data the two simulation parameters t_{int} and Q_{crit} are varied. t_{int} is vaired between 5 and 140 ns and Q_{crit} between 1x10^6 and 9x10^6. The parameter values which do agree best with the measurements are determined by a χ^2 minimisation.

4. Preliminary results

A preliminary comparison of the measured and simulated discharge probability as a function of the absolute gain is presented in Figure 3. A good agreement between experimental data and simulation over several orders of magnitude can be achieved by taking only primary ionization and basic gas properties into account. This shows that the charge density in single THGEM holes is the main protagonist leading to discharges in THGEM-based detectors. The best agreement between simulation and measurement is achieved for an t_{int} of 25 ns for Ar–CO_2 (90–10) and 18 ns for Ne–CO_2 (90–10). From the simulation also the critical charge Q_{crit} can be extracted. For Ar–CO_2 (90–10) and Ne–CO_2 (90–10) a Q_{crit} of 2.5x10^6 electrons per THGEM hole respectively 7.0x10^6 electrons per THGEM hole is determined. Given the dimensions of a typical THGEM in Section 2 the volume of a single THGEM hole can be determined to be 0.05027 mm^3. With the volume given, the critical charge per THGEM hole Q_{crit} can be converted to a charge density. Therefore, the charge density necessary to trigger a discharge in a single THGEM hole can be given. In Ar–CO_2 (90–10) the Q_{crit}corresponds to a charge density of around 8 pC mm^{-3} and in Ne–CO_2 (90–10) to around 22 pC mm^{-3}. The discharge probability in Ar–CO_2 (90–10) is higher by several orders of magnitude than in Ne–CO_2 (90–10) for a given gain. This difference can be explained by comparing the basic gas properties of the corresponding noble gases. The number of primary electrons liberated by an incident alpha particle is higher in Argon due to the lower effective ionisation potential and the range of alpha particles in Ar-based mixtures is about 40 percent shorter than in Ne-based mixtures resulting in higher local charge densities in Ar-based gas mixtures [6]. Therefore the critical charge limit is more likely to be exceeded and thus a higher discharge probability is observed.

The critical charge limits for both gases are consistent with the Raether limit.

The extracted Q_{crit} values for THGEMs in both gas mixtures are compared with those of a similar study in the same gases for GEMs [6], see Table 2. Even though the Q_{crit} values for the THGEM from this work are preliminary and for the time being given without an error estimation one can try to compare THGEM and GEM by their respective Q_{crit} in different gases. Making this comparison one

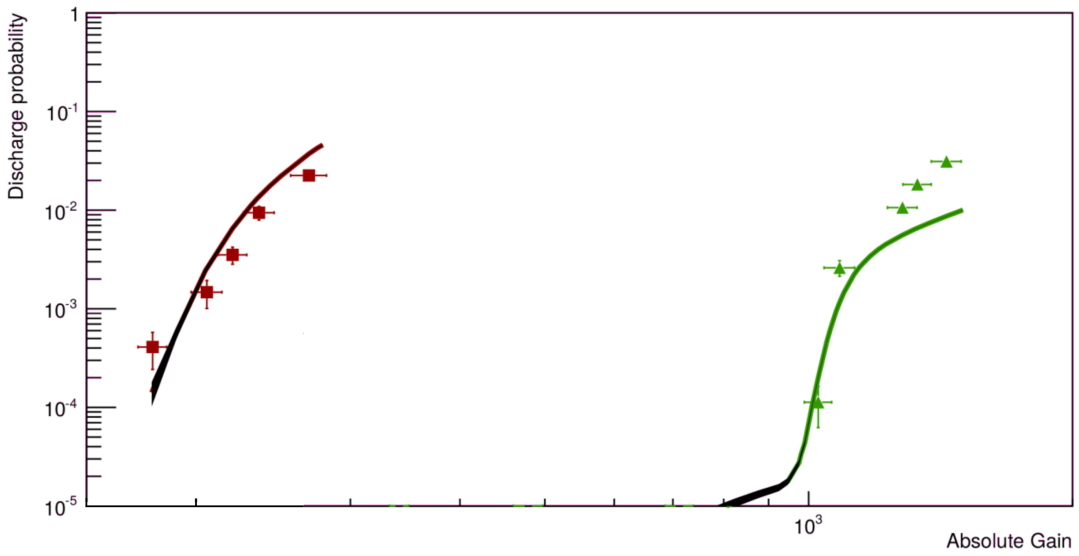

Figure 3. Discharge probability as a function of absolute gain. The lines indicate the results of the simulations while the points correspond to measurements. The integration time in the simulation for Ar–CO_2 (90–10) is 25 ns and for Ne–CO_2 (90–10) 18 ns. Note that in the depiction of the simulation outcomes uncertainties are yet to be included.

can see that for both technologies the Q_{crit} is of the same magnitude. The effect of the gas mixture on the Q_{crit} is more pronounced than the design difference of THGEM and GEM.

5. Summary and outlook

We have presented preliminary results of an ongoing study of the charge density as main factor for discharges in THGEM-based detectors in Ar–CO_2 (90–10) and Ne–CO_2 (90–10). Our findings show that the accumulation of charges in single THGEM holes is the main reason for the discharge formation in THGEM detectors.
By simulating the energy deposition of alpha particles and the drift of the created ionisation electrons while taking just basic gas properties and primary ionization into account, we are able to reproduce the experimentally measured discharge probability. By counting the charges inside a single THGEM hole and normalizing by the total number of emitted alpha particles we obtain the critical charge Q_{crit}. Exceeding this limit will lead to a discharge. Comparing simulated and measured data allows us to extract this critical charge Q_{crit} for different gas mixtures. We report a Q_{crit} of 2.5x10^6 electrons per THGEM hole for Ar–CO_2 (90–10) and 7x10^6 electrons per THGEM hole for Ne–CO_2 (90–10). Those values are compatible with the Raether limit and previous studies in GEMs [6].
Further measurements and analysis are ongoing.

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