Progress towards a THGEM-based detector of single photons


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Abstract

The novel and robust Thick GEM (THGEM) electron multiplier, coupled to a solid state photon converter, represents a promising option for instrumenting, at affordable costs, large areas with photon detectors, in particular, in Cherenkov imaging counters where single photons must be detected with high efficiency. The main goal of our project is to demonstrate the feasibility of reliable gaseous detector of single photons based on the use of THGEM multipliers, able to stably operate at high gain and high rate and to build and validate a large size prototype of such a detector. The project status and perspectives are reported; in particular attention is dedicated to the simulation and laboratory studies performed to understand the photo-electron extraction performance attainable using a solid state coated photo-cathode film onto a THGEM substrate.

1. Introduction

Potentially THGEM based detectors match all the requirements imposed by the coming third generation of photon detectors for RICH application, provided parameters and production techniques are properly chosen. THGEMs [1,2] are electron multipliers derived from the GEM design, scaling the geometrical parameters and changing the production technology: they are PCBs and the holes are obtained by drilling. A metal-free clearance ring, the rim, surrounding the hole, is obtained by Cu etching. In addition to typical GEM features (closed geometry and fast signal) the choice of this type of detector is motivated by the high gain and simplicity of production (standard PCBs technique), robustness against sparks and mechanical self supporting structure. Multistage structures, where the first THGEM layer is coated with a photosensitive CsI film, guarantee UV light sensitivity, allow to obtain gas multiplication factors $Z \geq 10^5$, high rate operation, and provide fast pulses with a few nanosecond rise-time. The reduction of photon and ion feedback and the related photo-cathode bombardment is obtained thanks to the closed geometry structure: this architecture can overcome the limitations affecting the present generation of gaseous photon detectors based on open geometries. Even if THGEM based detectors cannot be built with very low material budget and cannot achieve the GEM’s excellent spatial resolution, these characteristics do not represent a limitation when used as single photon gaseous detectors in Cherenkov imaging applications. Moreover the reduced gaps between the multiplication stages allow to operate successfully the detectors in magnetic field.

THGEM characterization versus the various geometrical and production parameters are reported in Section 2. The behavior of THGEM photon detectors are reported in Section 3. Conclusions and outlook are provided in Section 4.

2. THGEM characterization

The characterization of each THGEM detector is performed measuring the gain from signal amplitude spectra and from current measurements at the anodic plane. The typical setup is illustrated in Fig. 1. The THGEM electrodes are kept at potentials $V_1$ and $V_2$...
generating the dipole field $E_M$, while the wires at a distance $d_2$ from the top electrode are at $V_1$ potential so defining the drift field $E_D$. The signal is collected at the anodic plane set at $V_0$, usually ground, at a distance $d_1$ from the bottom electrode, defining the induction field $E_i$. In case of multiple stages THGEM detector the field between two multiplication layers is named transfer field $E_T$. A single THGEM layer with active surface of $30 \times 30$ mm$^2$, is positioned inside an aluminum chamber in a Argon CO$_2$ (70/30) gas atmosphere, and is irradiated by X-Ray ($^{55}$Fe source). THGEMs with different hole size, thickness from 100 to 600 $\mu$m have been tested applying the $E_D$ field which maximizes the gain preserving stable working condition [3]. The results can be summarized as follows:

- no rim THGEMs can stand lower $\Delta V = V_2 - V_1$ compared to THGEMs with rim;
- large rim THGEMs can provide larger gain;
- no rim or small rim ($\leq 15 \mu$m) THGEMs are characterized by very small gain variation as function of time and of their irradiation history while larger rim ones ($\sim 100 \mu$m) present gain variations $\gg 2$[3];
- the maximum achievable gain is proportional to the inverse of the hole diameter, while it depends only marginally on the pitch dimension;
- among the different production techniques the Global Etching procedure [4] has been chosen: comparing THGEM with the same geometry, higher $\Delta V$ can be applied;
- maximum rate tests, measuring the linear response of the current as function of the irradiation rate, have shown that THGEMs with small rim can stand high single photon rates in the order of $\sim 35$ MHz/mm$^2$, while deviation from linear behavior can be detected in case of larger rim dimensions. A X-ray Cu collimated source has been used for these studies [3].

We have chosen THGEMs with small rim to obtain stable gain operation, even if these devices do not allow for extremely high gains. High gain operation can be recovered adopting multistage architectures: gains up to $10^6$ have been obtained with a detector formed by a triple structure of small rim ($10 \mu$m rim) THGEMs [4]. The electric fields to be applied above and below the THGEM have been optimized by energy resolution measurements performed with the setup shown in Fig. 1. This corresponds to measure the primary charge collection efficiency; the drift and induction fields have been varied irradiating the detector with an X-ray source ($^{55}$Fe). Good energy resolution, corresponding to full primary charge collection, can be obtained only with small rim size. When the rim size is increased the full charge collection efficiency deteriorates at drift field $\sim 2$ kV/cm or for larger rims ($100 \mu$m) is never reached for reasonable field values (Fig. 2). Contrary to the drift field case the induction field variation mildly affects the energy resolution, which is pretty constant and ranges between 22% and 30%.

3. THGEM-based photon detector

The structure of a THGEM based photon detector is illustrated in Fig. 3. For the three THGEM layers we have chosen the following geometry: hole diameter 0.4 mm, pitch 0.8 mm, thickness 0.4 mm and rim size $\sim 10 \mu$m. The distance between THGEMs, kept via Peek$^1$ spacer is 2 mm. Several critical aspects need to be investigated when using the detector in photon sensitive mode, in particular the effective CsI Q.E., which depends on the gas and on the electric field. It has been shown that the best effective Q. E. is obtained with pure methane or noble gas-methane mixtures and electric field not lower than 500–1000 V/cm [5,6]. In this condition the photoelectron loss due to back-scattering is minimum. Simulation exercises (Fig. 4) complemented by measurements (Fig. 5) are used to investigate the photoelectron collection efficiency. The field at the photocathode surface is the combination of the electric field due to the potential $\Delta V$ applied between the two THGEM faces and the drift field $E_D$. Electron trajectory simulations indicate that when $E_D$ points out from the wire electrode, part of the photoelectrons are not focused into the holes: they are lost (Fig. 4, center). For zero $E_D$ field all the electron trajectories enter the holes (Fig. 4, left), while when the additional field is oriented towards the photocathode, the resulting field at the photocathode surface is reduced and at part of the surface is too feeble to guide the electrons into the THGEM holes (Fig. 4, right). Summarizing, the optimum configuration is obtained applying $E_D = 0$. The behavior predicted by the simulations has been confirmed by measurements in methane atmosphere of the photocurrent induced by a UV lamp at the anode of a detector consisting of a single THGEM coated with a CsI film. The plots in Fig. 5 clearly indicate a sharp current decrease when the $E_D$ field is pointing from the photocathode (negative field values), a rough plateau for moderate values of the additional field oriented towards the photocathode (positive field values), followed by a drop when the total field becomes too low. In particular, the current drops at lower values of the additional field when the potential applied between the THGEM faces is smaller,

$^1$ Polyether ether ketone (PEEK).
namely for lower dipole field as expected from the simulation. Using Ar-CH₄ mixtures large dipole voltages can be applied, favoring the photo electron extraction efficiency. When coupled with the electronic read out chain based on the MAD-4 front-end chip [7] and the F1 TDC [8], fully described in [9], the detector presents a time resolution better than 10 ns, as illustrated in Fig. 6: this result is obtained illuminating the detector with a pulsed UV lamp in single photon mode. A prototype of THGEM-based photon detector, with the geometrical parameters given above, has been operated during 2009, in a test beam at the CERN H4 beam line, providing evidence of Cherenkov light detection (Fig. 7). The signals are collected at an anode plane segmented in 16 pads with active surface of 7.7 x 7.7 mm² and 8 mm pitch and read out by the same electronic chain described before. Stable behavior of the detector has been observed at gain of ~10⁵ with a 150 GeV/c π beam rate of 10⁴/s and beam σₓ = σᵧ = 20 mm. Further tests in a beam line are foreseen in August 2010 aiming at performing photon counting measurement, a deeper understanding of the time development of the signal and further time stability studies.

4. Outlook and conclusions

Some features of the THGEM-based photon detector still require deeper studies: the closed geometry architecture of THGEM detectors is suited to limit the Ion Back Flow, defined as the part of the ions generated in the multiplication process and impinging back on the photocathode surface. The intermediate layers in fact can be used as traps to capture the ions flowing back. Using a triple THGEM architecture the IBF is reduced at about 20% of the total ion flow, while the suppression should be an order of magnitude more effective. The interesting solution of the THCOBRA [10] structure for the bottom electrode of the first THGEM imposes constrains on the THGEM hole size over the pitch ratio, due to the minimum space between THCOBRA pistes imposed by PCB technology. This solution appears moreover extremely challenging from the technological point of view: the minimum possible insulation distance between the pistes is ~ 100 µm² and the control of this parameter when producing large surface detectors is difficult. Moreover thin pists are less robust against discharges. For this reason other approaches are under study, for example the use of a fine mesh of wires in between the holes has proved to reduce the IBF rates to about 5% of the ion Back Flow.

Fig. 4. Electron trajectories, simulated using the Garfield package, while the electric field is calculated using the Ansys package, for three different drift field configurations: 0, +500 and +500 V/cm. The THGEM ΔV applied is 1.5 kV/cm, the geometrical parameters of the THGEM are: holes 0.4 mm, pitch 0.8 mm and 0.4 mm thickness. The multiplication process in the gas (Ar/CO₂) 70/30 is switched off.

Fig. 5. Anodic current measured in a single THGEM detector with CsI reflective photocathode versus Eₓ⁰; the different point sets have been obtained for different values of the potential ΔV applied between the THGEM faces in Ar/CH₄ 66/34 gas mixture.

Fig. 6. Time distribution spectrum.

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back-flow without gain losses. More sophisticated structures are under analysis and will be tested in the near future.

When the detector size is increased, it must be taken into account that in case of discharges between electrodes both inefficiency of the full detector area and possible damages to the electrodes and to read out electronics can occur. Segmentation of the detector surface is the natural solution to avoid these events. Tests to determine minimum space separation needed to exclude the next segmented area in case of discharges have been performed measuring the maximum $\Delta V$ that a strip structure can stand for different strip sizes and strip distances. The results is that a separation of 1 mm is enough to stand $\Delta V \sim 2$ kV, implying that the effective reduction of photosensitive area for the first THGEM is negligible.

The characterization of the THGEMs has proved to be fundamental in understanding the role of the different parameters and in their choice, moreover the photo-electron extraction processes are understood and electrostatic simulations have proved to be a reliable tool. The preliminary results of the 2009 test beam have been presented showing that THGEM based photon detector for Cherenkov light can be operated with stable behavior at gain of $10^5$ with a time resolution below 10 ns. In spite of some open questions, the results obtained make us confident to converge towards robust and effective gaseous photon detectors.

Appendix A. Supplementary data

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.nima.2010.10.117.

References