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Design and function of an electron mobility spectrometer with a thick gas electron multiplier

Gloria M. Orchard [a,*], Silvia Puddu [b], Anthony J. Waker [a]

[a] Faculty of Energy Systems and Nuclear Science, University of Ontario Institute of Technology, Oshawa, Ontario, Canada, L1H 7K4
[b] CERN, 1211 Geneva 23, Switzerland and University of Bern, LHEP, Sidlerstrasse 5, 3012 Bern, Switzerland

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ABSTRACT

The design and function of an electron mobility spectrometer (EMS) including a thick gas electron multiplier (THGEM) is presented. The THGEM was designed to easily be incorporated in an existing EMS to investigate the ability to detect tritium in air using a micropattern gas detector. The THGEM and a collection plate (anode) were installed and the appropriate circuitry was designed and connected to supply the required voltages to the THGEM-EMS. An alpha source (^{241}Am) was used to generate electron-ion pairs within the gas-filled sensitive volume of the EMS. The electrons were used to investigate the THGEM-EMS response as a function of applied voltage to the THGEM and anode. The relative gas-gain and system resolution of the THGEM-EMS were measured at various applied voltage settings. It was observed a potential difference across the THGEM of +420 V and potential difference across the induction region of +150 V for this EMS setup resulted in the minimum voltage requirements to operate with a stable gain and system resolution. Furthermore, as expected, the gain is strongly affected not only by the potential difference across the THGEM, but also by the applied voltage to the anode and resulting potential difference between the THGEM and anode.

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1. Introduction

The presence of tritium, a short range (~6 mm in air) and low energy beta emitter (E_{max}, 18.6 keV) in the workplace of heavy water power reactors creates a challenging monitoring environment, especially if in the presence of gamma radiation and noble-gas radionuclides. The low detection efficiency of tritium and discrimination against other radiation types is an ongoing issue for all detector designs [1] but due to the high affinity of oxygen for electrons the efficiency of tritium detection in air using proportional counters or other micropattern gas detectors is further decreased. However, the motivation to develop a gas multiplication device as a tritium monitor stems from the principle that by incorporating tritiated air within the counting gas, both the counting efficiency and sensitivity can be maximized as well as the potential for gamma and noble-gas discrimination [2]. As part of this development work, an Electron Mobility Spectrometer (EMS) was recently constructed by Orchard and Waker [3] to look at electron mobility in various counting gases using a proportional counter to collect the electrons created within and drifted through the EMS, and was used to study the gas multiplication properties of proportional counters and their properties for measuring tritium in air.

Studies with the anode-wire configuration of the EMS yielded parameters such as the drift time of electrons, the pulse formation time in the gas multiplication region and relative gas-gain [3]. However, the use of an anode wire and its geometry within the EMS limited the ability to measure the drift time of electrons and pulse formation time independently. The use of a robust and easy to fabricate device that would provide a confined gas multiplication region [4] would reduce the uncertainty in timing measurements and for this reason a thick gas electron multiplier (THGEM) has been designed and integrated into the EMS of Orchard and Waker [3].

In this article the THGEM-EMS design and experimental setup are described and the THGEM-EMS response as a function of operating voltages is observed and compared to the anode-wire EMS configuration presented in [3]. The THGEM-EMS operating voltages are investigated using the ideal EMS operating conditions described in Orchard and Waker [3]. A set of systematic measurements were conducted and the relative gas-gain and system resolution as a function of applied voltages to the THGEM and induction region are presented.

* Corresponding author.
E-mail addresses: gloria.spirou@gmail.com (G.M. Orchard), anthony.waker@uoit.ca (A.J. Waker).

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2. Experimental design and method

The THGEM was first introduced in 2002 by Periale et al. [5] and was developed based on the gas electron multiplier (GEM) which was introduced in the mid 1990' s [6,7]. The THGEM is a proportional counter using a hole type structure and can be related to the category of micropattern gas detectors [8]. Initial studies using the THGEM for various detection purposes can be found in Breskin et al. [9] and Orchard et al. [10] and references presented within [9,10]. A THGEM is composed of an insulating sheet, such as FR4, which is coated on both sides with a conducting material, such as copper, and can be easily fabricated using standard printed circuit board (PCB) manufacturing techniques. The THGEM contains many sub-millimeter diameter holes generating a strong electric field within the holes when a voltage is applied across the conducting layers. The presence of the strong electric field within the holes generates an electron avalanche as electrons travel through the holes in the presence of a counting gas. The study and advancement of THGEMs in various detector applications is ongoing and references [11–16] represent a selection of recently reported investigations.

The THGEM for this study was designed to be incorporated within the existing EMS described in Orchard and Waker [3]. The existing anode wire was removed and the THGEM along with a brass collection plate (CP) were installed. The EMS was operated with a HV_{EMS} of -1600 V, at atmospheric pressure (p) with an electric field (E) strength of ~274 V/cm using P-10 (90% Ar, 10% CH_4) as the counting gas. These EMS operating conditions result in an E/p value of 0.36 V/cm/mm Hg within the EMS gas sensitive volume, corresponding to the minimal electron attachment region for oxygen [3]. Fig. 1 is a schematic of the EMS and associated pulse processing electronics required for the operation of the EMS. Four high voltage supplies, HV_{EMS}, HV_{SB}, HV_{THGEM} and HV_{CP} were used independently to supply the required voltages to the EMS, the surface barrier (SB) detector, the THGEM and CP, respectively. The preamplifiers (PreAmp), amplifiers (Amp) and multichannel analyzer (MCA) were used to process the detected pulses. A mass flow controller (MFC) was used to flow gas continuously through the EMS sensitive volume (SV) at a rate of 50 cm^3/min. The dashed lines in Fig. 1 represent the additional electronics, an amplifier and a gate and delay generator (G&D), required to measure the transit time of electrons within the EMS by gating the MCA. The ^{241}Am alpha source (0.1 µCi, January 2011, Eckert & Ziegler) is used to generate electron ion pairs within the EMS sensitive gas volume. The electrons travel through the drift region of the EMS, and into the drift region of the THGEM. Gas multiplication occurs within the holes of the THGEM, and the collection plate is the anode where the emerging electrons from the THGEM holes are collected. The surface barrier detector is used to detect the alpha particles, and is used as a visual check to ensure the presence of charge carriers within the gas cavity. The surface barrier is also used as the trigger when the EMS is used to measure the transit time of electrons as described in [3].

The THGEM was designed using *Altium Designer* software and manufactured by *Omega Circuits* (Scarborough, Canada). The THGEM is a flat disc with a diameter of 41 mm composed of a 0.12 mm thick FR4 insulator. The active region of the THGEM is centered on the flat disc with a diameter of 17 mm and each side coated with copper, resulting in a total thickness for the active region of 0.17 ± 0.01 mm. There are 293 holes within the active region each with a diameter of 400 µm, pitch of 800 µm and a 100 µm rim. A schematic of the THGEM is shown in Fig. 2(a). Fig. 2 (b) is a schematic of the electric circuit used to create a voltage drop across the THGEM copper layers. This circuit design is based

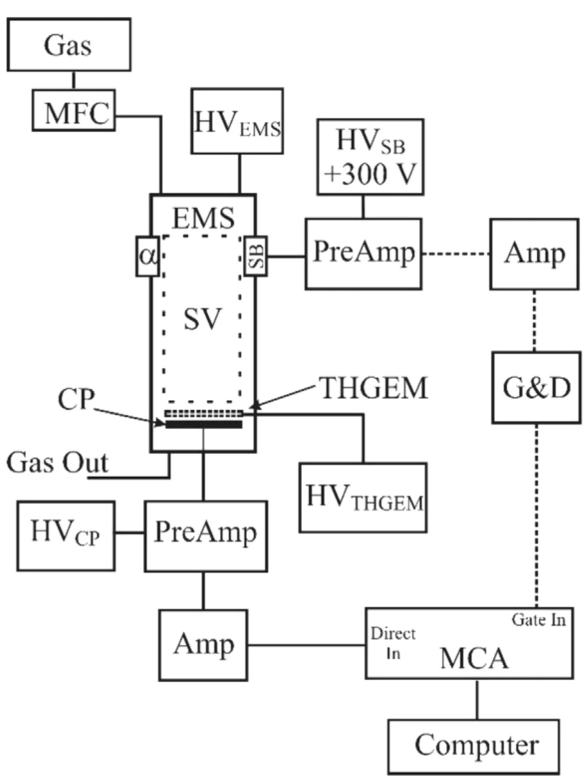

Fig. 1. Experimental setup of THGEM-EMS. The thick gas electron multiplier (THGEM) and collection plate (CP) were incorporated in place of the preexisting anode wire to study the THGEM properties. The α symbol represents the location of the ^{241}Am alpha source.

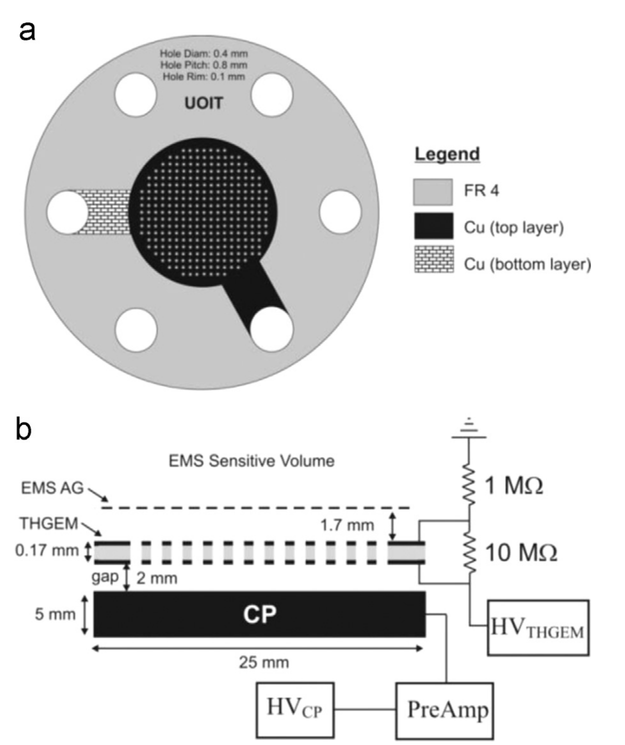

Fig. 2. (a) Schematic design of THGEM used to incorporate within existing EMS. The active area (diameter of 17 mm) is defined by the copper layers centered on the THGEM. The overall diameter is 41 mm. Two copper electrical contacts (one on each side of the FR4) were extended from the active area to the holes located near the edge of the FR4 and used to connect the high voltage circuit as shown in (b). The EMS aperture grid (EMS AG) is located 1.7 mm above the THGEM and separates the EMS drift region and the THGEM drift region. The induction region is the 2 mm gap between the bottom of the THGEM and the surface of the collection plate (CP). (Diagrams not drawn to scale).

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