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Development of a thick gas electron multiplier for microdosimetry

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ABSTRACT

A new tissue-equivalent proportional counter based on a thick gas electron multiplier (THGEM) was developed and tested for microdosimetry. A systematic test was conducted at the McMaster Accelerator Laboratory to investigate the overall performance of the prototype detector. A mixed neutron–gamma-ray radiation field was generated using the ^{7}Li(p,n) reaction. The detector was operated at low voltage initially to test the stability and then the relative multiplication gain was measured as a function of the operating high voltage. A drift potential of 100 V and a THGEM bias of 727 V generated a multiplication gain sufficient for the detection of both neutron and gamma-ray radiation. A consistent microdosimetric pattern was observed between the THGEM detector and standard TEPC for microdosimetry.

1. Introduction

One of the goals in experimental microdosimetry is to measure the absorbed dose as a spectrum of individual energy depositing events in microscopic volumes of tissue, which can be related to the distribution of dose in terms of linear energy transfer (LET) [1]. Different types of ionizing radiation can lead to different biological effects. The biological effects depend on the pattern in which a given amount of energy is deposited in the irradiated medium. This is related to the LET associated with different types of ionizing radiation and the level of biological detriment and is quantified using the relative biological effectiveness (RBE) for a given radiation [2]. Low pressure tissue-equivalent proportional counters (TEPCs) are a versatile tool in radiation physics, radiation protection and radiation biology, and are used to measure the absorbed dose spectrum in microscopic tissue volumes. The traditional spherical TEPC is the most common detector currently used for microdosimetry. In the study presented here, a new type of TEPC based on a thick gas electron multiplier (THGEM) is described. This is a new type of proportional counter developed to overcome the dose rate limitation in classical TEPCs and can be implemented as a two-dimensional microdosimetric detector.

The concept of a proportional counter using a hole type structure has been studied since the mid 1990s with a strong research interest continuing today. Some early references include Sakurai et al. [3] and Sauli [4]. A common name for this type of proportional counter is the gas electron multiplier (GEM) and it is composed of a thin sheet of insulator which is coated on both sides with a conducting material, such as copper. The GEM also contains many microscopic holes that allow an electric field to be generated within them when a voltage is applied across the conducting layers. Depending on the strength of the electric field generated across the holes, electron multiplication can be observed when electrons are accelerated through these holes. A proportional counter (PC) based on a capillary plate was reported by Sakurai et al. [3] in 1996 and a TEPC based on a GEM by Farahmand et al. [5] in 2003 and by Dubeau and Waker [6] in 2008. More recently, the THGEM has emerged which is a larger version of the GEM. The THGEM contains a thicker insulating layer and larger diameter holes. Compared with the GEM, the THGEM is easier to fabricate and is cost-effective. It was first introduced in 2002 by Periale et al. [7] and initial studies were reported in 2003 [8,9]. Further studies and advances on the THGEM and applications have been reported and continue to be investigated [10–17].

In this article we describe the experimental conditions applied to the THGEM TEPC and the corresponding results obtained using a mixed neutron–gamma-radiation field. The initial conceptual design of the THGEM and simulation studies are reported in Byun et al. [18]. Using tissue-equivalent (TE) materials the prototype detector was assembled and connected to a preamplifier followed by two pulse processing systems in parallel. One of the main goals of this study was to investigate the ability of the detector to obtain the expected microdosimetric spectrum as observed when using a standard TEPC. The relative multiplication gain with respect to the voltage across the THGEM was also studied. Future investigations due to the results obtained from these experiments will also be discussed.

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2. Experimental design, method and materials

2.1. Thick GEM TEPC

The overall volume of the detector assembly is 5 cm × 5 cm × 1 cm and is housed in an aluminum casing. The THGEM foil is composed of a 0.12 mm thick FR4-epoxy insulator coated with copper on both sides having a total thickness of ~0.24 mm. The THGEM contains 32 holes each with a diameter of 0.35 mm and pitch of 0.64 mm. The sensitive volume of the detector is a right cylinder with a diameter of ~5 mm and height of ~5 mm and is located in the center of the detector assembly.

Fig. 1(a) is a picture of the detector within the aluminum casing and (b) is a microscopic view of the THGEM plate displaying a few of the holes. The edges of the holes are etched after drilling to clean the copper and ensure no copper fragments are left within the holes. Once the detector components are cleaned and assembled, it is sealed and placed on a vacuum pump to remove as much of the trapped air as possible. Generally, the detector is left on the pump for at least two days and the pressure drops to below 1×10^{-5} Torr. After pumping, the detector is filled with tissue-equivalent (TE) propane gas at a pressure of 167 Torr, which simulates a 2 μm diameter right cylindrical volume of unit density soft tissue within the sensitive volume of the detector. TE propane gas is composed of 55% propane, 39.5% carbon dioxide and 5.5% nitrogen.

As wall materials, both tissue-equivalent conductors and insulators were used to simulate a tissue-equivalent environment surrounding the sensitive volume as shown in Fig. 2 (a cross-section schematic of the detector). The drift cathode and bottom layers are A-150 conducting TE plastic and the insulating layers are made of rexolite, which is also a TE material. Cylindrical holes aligned with the THGEM holes are mechanically drilled through the center of the two rexolite layers to create the sensitive volume and to allow for the collection of emerging electrons from the bottom of the THGEM by the collection plate. The collection plate is connected in DC coupling to the preamplifier. The high voltage (HV) connections are also displayed. As shown in Fig. 2, the THGEM is placed between the rexolite material which is located between the A-150 TE plastic. A thin layer of rexolite is placed between the THGEM and collection plate (anode) to separate the THGEM from the anode which collects the electrons once they emerge from the THGEM holes. Two narrow gas flow channels located on the top and bottom of the 4.9 mm thick rexolite wall allow for pumping and filling of the sensitive volume (SV).

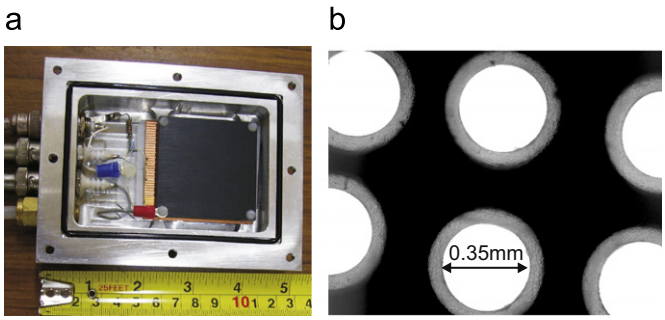

Fig. 1. (a) Picture of THGEM TEPC detector within the aluminum casing and (b) microscopic view of THGEM holes.

The cathode was biased independently using HV1 while the top and bottom surfaces of the THGEM were biased from a common bias supply, HV2. The HV2 voltage applied to the detector ranged from −500 to −820 V. The voltage, HV1, applied to the drift cathode was always maintained at least 100 V more negative than HV2. ΔV_{Drift} is used to denote the drift potential, i.e. the voltage difference between the drift cathode and the top of the THGEM. The resistors R1 and R2 are chosen such that most of the voltage is applied across the THGEM and the remainder is used to direct the electrons to the collection plate. In the data presented here a resistance of 10 MΩ for R1 and 1 MΩ for R2 was used. It was observed that the range of 45–75 V for the collection potential was sufficient to collect the electrons emerging from the bottom of the THGEM.

2.2. Experimental setup

A mixed neutron–gamma field was used to test the THGEM detector. The Tandetron accelerator at the McMaster Accelerator Laboratory was used to generate a neutron–gamma field. A fast neutron field is generated by a thick lithium target via the ^{7}Li(p,n) reaction. A competing ^{7}Li(p,p′γ) reaction generates 478 keV γ-rays. An irradiation cavity was built to enclose the radiation for use in *in vivo* animal and human studies. A detailed description of the irradiation cavity can be found in Refs. [19,20]. The proton current was set to 150 μA with a proton energy of 2.3 MeV resulting in neutron energies ranging from ~30 to 550 keV [21].

The THGEM TEPC was placed in the irradiation cavity and centered on the beam axis. The detector output was connected to a preamplifier (model A250CF CoolFET, Amptek or model 142A ORTEC) and the preamp signal was sent to a shaping amplifier. The signal was then split and received by two pulse processing systems. The conventional analogue system (CAS) and the real time system (RTS) [22] independently analyzed the pulse height in linear scale and logarithmic scale, respectively. The RTS accumulates the dose spectrum in comparison to the frequency spectrum that is accumulated by CAS. The RTS was developed by

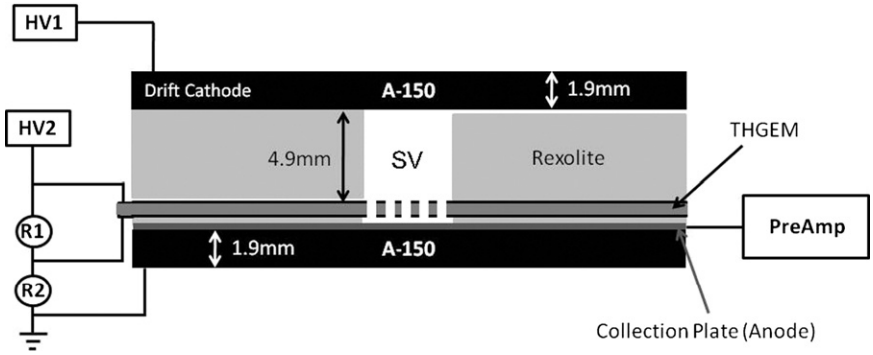

Fig. 2. Cross-section of the THGEM TEPC. (Figure is not to scale, actual THGEM thickness is ~0.24 mm.) The sensitive volume (SV) is filled with TE propane gas. HV1 is used to supply voltage to the drift cathode and HV2 is used to supply voltage to create the electric fields for electron multiplication and collection.