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# Development of a multi-element microdosimetric detector based on a thick gas electron multiplier

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ABSTRACT

A prototype multi-element gaseous microdosimetric detector was developed using the Thick Gas Electron Multiplier (THGEM) technique. The detector aims at measuring neutron and gamma-ray dose rates for weak neutron-gamma radiation fields. The multi-element design was employed to increase the neutron detection efficiency. The prototype THGEM multi-element detector consists of three layers of tissue equivalent plastic hexagons and each layer houses a hexagonal array of seven cylindrical gas cavity elements with equal heights and diameters of 17 mm. The final detector structure incorporates 21 gaseous volumes. Owing to the absence of wire electrodes, the THGEM multi-element detector offers flexible and convenient fabrication. The detector responses to neutron and gamma-ray were investigated using the McMaster Tandetron $^{7}$Li(p,n) neutron source. The dosimetric performance of the detector is presented in contrast to the response of a commercial tissue equivalent proportional counter. Compared to the standard TEPC response, the detector gave a consistent microdosimetric response with an average discrepancy of 8 % in measured neutron absorbed dose. An improvement of a factor of 3.0 in neutron detection efficiency has been accomplished with only a small degradation in energy resolution. However, its low energy cut off is about 6 keV/μm, which is not sufficient to measure the gamma-ray dose. This problem will be addressed by increasing the electron multiplication gain using double THGEM layers.

## 1. Introduction

Tissue Equivalent Proportional Counters (TEPCs) are considered the standard instrument for microdosimetry [1], aiming at measuring the distribution of the energy deposited by ionizing radiation in a micrometric target, and has been employed for a number of radiation physics, radiation protection and radiation biology applications for many decades [2–6]. Particularly, owing to its excellent capability of decomposing different linear energy transfer components, the TEPC-based instruments have been widely used for measuring radiation doses for mixed neutron-gamma radiation fields where accurate determination of the photon and neutron doses is desired [7–9].

The basic structure of a traditional TEPC [10] includes a spherical gas cavity in a conducting tissue equivalent A-150 plastic [11] with a central anode wire. Operated in the pulse mode, the TEPC provides a pulse height distribution of amplified signals that are proportional to the individual energy deposition events inside the gas cavity. Since TEPC-based dosemeters are built using tissue equivalent materials, they have a sound physical foundation in determining the radiation dose [1,12].

In spite of the excellent tissue equivalent material composition, small TEPCs are not suitable for the neutron dose rates generally encountered in nuclear power plants since their neutron detection efficiency is low, resulting in impractically long counting time. Larger TEPCs, typically 5 in. dia., are certainly better suited, however, they are not sensitive enough for weak fields. This shortcoming arises from the low cross section of the neutron elastic scattering with proton in contrast to the $^{3}$He(n,p) and $^{10}$B(n,$\alpha$) reactions that are commonly employed in moderator-based neutron dosemeters [13].

As a solution for the low efficiency problem, a so-called “multi-element” structure, consisting of an array of gaseous cavities rather than a single volume, can improve the neutron detection efficiency greatly while it allows keeping the overall detector size relatively small [14–16]. However, building a multi-element detector using the traditional proportional counter technology is extremely challenging and expensive, particularly when the dimensions of the individual sensitive volumes are reduced.

For the last decade, TEPC-based instruments have been developed by a few groups using alternative techniques [17–21] as reviewed explicitly by Agosteo [22]. Among them, the most advanced imple-

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mented techniques are Gas Electron Multiplier (GEM) [23] and more recently THick GEM (THGEM) [24] that use hole-type structures for electron multiplication. Unlike the standard GEM which uses polyimide foil with etched holes, the THGEM can be manufactured industrially using standard printed circuit board (PCB) techniques, allowing the holes to be machined by drilling. This makes THGEM fabrication inexpensive and flexible. The THGEM, descendant of the standard GEM with the physical dimensions of holes, pitch and thickness up to one order of magnitude larger, provides a confined gas multiplication region within sub-millimeter diameter holes. THGEMs were studied and implemented by several groups over a broad range of applications reviewed in Ref. [25,26].

To address the structural complication that is unavoidably encountered with the traditional technology, a THGEM-based multi-element neutron dosemeter was proposed in Ref. [16]. The Monte Carlo simulation results reported in ref. [16] gave clear insight on the neutron efficiency dependence on the multi-element geometry. In this article, we report a THGEM multi-element neutron detector consisting of 21 multi-elements that was developed as a proof of principle. The detector was designed and fabricated, founded on the Monte Carlo simulation study and the THGEM TEPC technology [16,21,27,28]. In the following sections, the prototype detector structure, the essential components and the design considerations are fully described. The result of the fundamental tests performed to ensure the proper operation and response stability of the detector are presented.

## 2. Detector description

Fig. 1 shows the layout of the prototype multi-element THGEM microdosimetric detector. As shown in the figure, the detector consists of three alternating layers of Rexolite insulator (Rexolite 1422, C-LEC Plastics, Inc.) hexagons. Each layer houses a hexagonal array of seven cylindrical gas cavity elements, known as the sensitive volumes, with equal heights and diameters of 17 mm so that the final detector structure consists of 21 sub-elements. To pump out the air and fill the sensitive volumes with the operating gas, a set of grooves has been machined on the top and bottom of the Rexolite insulator. The wall thickness between each sub-element was kept to at least 1 mm to satisfy the charged particle equilibrium condition for neutrons with the energies up to 10 MeV. In each layer, the Rexolite insulator is sandwiched between a 1 mm thick A-150 conducting plastic and a THGEM layer. The charge collection regions are located next to each THGEM layer and consist of common readout boards that are separated from the THGEM layer by employing an arrangement of ceramic spacers with a thickness of 1 mm.

As presented schematically in Fig. 2, for a single sub-element, the distinct gas regions provide three different functional areas: a) the conversion and drift region, b) the multiplication area and c) the charge collection gap. In this design, each A-150 layer serves as the cathode. The gas cavities in the Rexolite layers form conversion and drift gaps, in which the electrons are produced by ionization and drift along the electric field toward the THGEM layer. With the application of a high potential difference between the top and bottom of the THGEM, a strong electric field is produced inside the THGEM holes, where electron multiplication happens. The electric field strength inside the THGEM holes is strong enough to initiate an electron avalanche. After multiplication, by the use of a potential difference across the collection gap, the avalanche electrons are collected by a common collection electrode. The amplitude of the collected signal by the readout anode is linearly proportional to the total deposited energy of a single event. While each individual sub-element operates as an independent detector, the signal outputs of all layers are united to provide a single output.

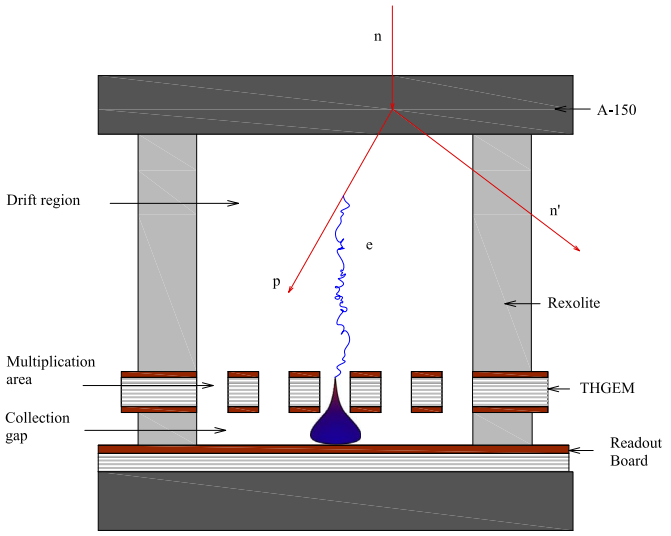


**Fig. 2.** A schematic view of different functional gas areas in a single gas cavity of the prototype THGEM-based detector.

It should be noted that for stacking layers, as shown in Fig. 1, the positions of the constituent materials for layer number 2 are mirrored to avoid having the cathodes and readout electrodes next to each other and minimize the leakage current across the neighbouring layers. As discussed in Ref. [16], it is expected that this configuration will have a slightly lower efficiency but a better angular response than stacking sequentially.

Fabricated using standard printed circuit board manufacturing techniques, the THGEM layout employed in this study is composed of a 0.4 mm FR4 insulator coated with 0.05 mm of copper on both

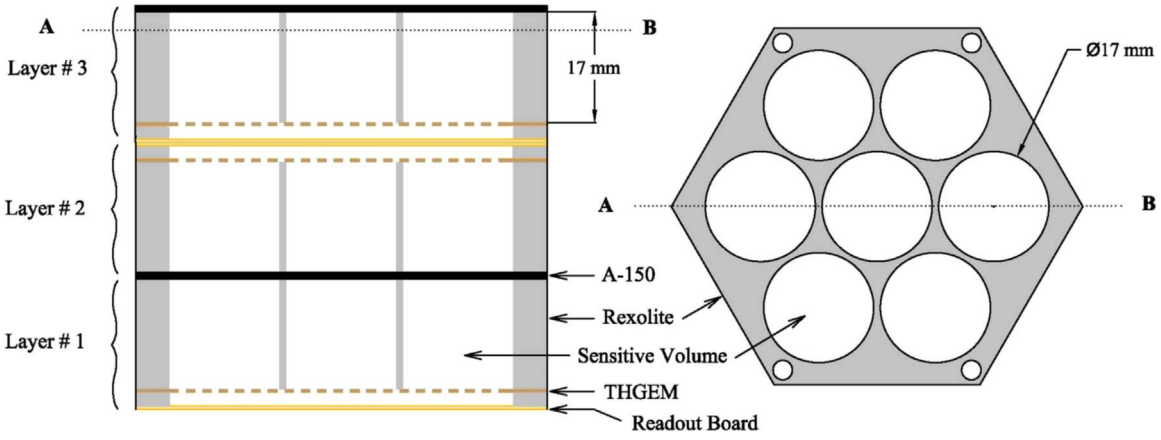


**Fig. 1.** Side and top cross sectional views of the prototype multi-element TEPC. Each Rexolite insulator layer houses a hexagonal array of seven cylindrical gas cavities with equal heights and diameters of 17 mm.