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Design a two-dimensional alpha surface contamination monitoring system using micro-pattern gaseous detectors (MPGDs)

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HIGHLIGHTS

- A new method for measuring alpha particles using the function of thick electronic multipliers in natural glow mode.
- Two-dimensional detection of alpha particles including fast response time and good spatial resolution.
- Determine the location and intensity of surface contamination with no need for electronic multiplier or reader system.

ABSTRACT

Addressed herein, a new monitoring method for alpha surface contamination based on the function of a thick gaseous electron multiplier (THGEM) in a self-quenching streamer mode (SQS) has been introduced. SQS mode detectors can detect alpha surface contamination in two dimensions. In the current study, the ability of thick gas electron multiplier detectors in SQS mode for two-dimensional monitoring of alpha surface contamination has been investigated by two Am-241 sources with activities equal to 33 and 150 kBq.m^{-3}. It has been found that the brightness is stronger in front of stronger sources. This may be attributed to the difference in contamination levels. It was also observed that the spatial resolution of the contamination rate depends on the number of holes per unit area of each THGEM. The advantage of this system is the ability to determine both the location and intensity of surface contamination with no need for an electronic multiplier or reader system.

KEYWORDS
Micro-pattern gaseous detectors
Thick gas electron multiplier
Self-quenching streamer mode
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1 Introduction

Surface contamination monitoring is important in the tracing of nuclear equipment contamination, environmental radioactive leakage, and the immediate assessment of nuclear accidents (Knoll, 2010). Traditional alpha detectors usually detect just the level of contaminations (Peskov et al., 2001). New monitoring equipment based on thick gas electron multipliers can be used for contaminant positioning (Xiao et al., 2019; Corradi et al., 2007). This type of surface contamination monitoring quickly measures the count rate and represents a plot of alpha radiation leakage (Hashemi and Negarestani, 2018).

The gas electron multiplier was invented in 1996 by Fabio Sauli (Sauli, 1997). Thick gaseous electron multiplier and resistive thick gaseous electron multiplier have been developed since 2000 in a new gaseous electron multiplier (GEM-like detector) design (Murtas, 2002; Altunbas et al., 2002). These perforated structures are usually fabricated using two metal surfaces with a 0.4 to 2 mm thickness of a dielectric layer in the middle, and 0.1 to 2 mm of the hole diameter (Hashemi and Negarestani, 2018; Souri et al., 2018).

One of the most important parameters in micro-pattern structures is the available efficiency of these detectors. It has been found that Raether's limit determines the maximum efficiency available in the most gaseous detectors including micro-pattern gaseous detectors (Xiao et al., 2019). In other words, micro-pattern structures (A_{max}) are limited by the following equation:

$$A_{max} \leq \frac{Q_{max}}{n_0} \tag{1}$$

where n_0 is the number of primary electrons and $Q_{max}(\approx 10^7 - 10^8)$ stands for the maximum available charge depending on the detector design (including gas composition and pressure). Very large values of A_{max} can lead to undesirable sparks in the detector which can be destructive for sensitive electronic devices. In the presence

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*Corresponding author: `m_mirhabibi@pnu.ac.ir` of some gas mixtures, the detector shifts to SQS mode after passing the proportional mode and, the beams of the self-quenching light reveal by the detector (Fig. 1). These beams do not cause any harmful effects, but the stability of this mode can be considered as an optical method for detecting particle traces. Thus, in micro-pattern gas detectors, by selecting the appropriate gas mixture to enter the SQS mode, the beams appear as soon as the total charger reaches the value of Q_{max}. A_{max} is considered as the threshold efficiency (A_{th}), to achieve SQS mode in micro-pattern structures. Therefore, in any GEM-like structure, at any certain voltage (i.e., transition voltage), the detector efficiency can reach A_{th} and the visible beams will appear in the detector (Hashemi and Negarestani, 2018).

2 Materials and methods

In the design and fabrication of the surface contamination monitoring system, thick electron multiplier plates have been applied. The thick electron multipliers plates include FR4 dielectric as a middle layer with a thickness of 0.4 mm and two thin copper sheets (0.35 mm thickness on both sides) (Fig. 2).

The holes are designed 0.4 mm in diameter with 1.0 mm distance. To prevent unwanted sparks at high voltages, the copper plate is cut from the edges of the holes to a thickness of 0.1 mm (Fig. 3).

3 Design and construction

Figure 4 shows a scheme of the structure of a thick gaseous electron multiplier detector whilst Fig. 5 shows its measurement setup.

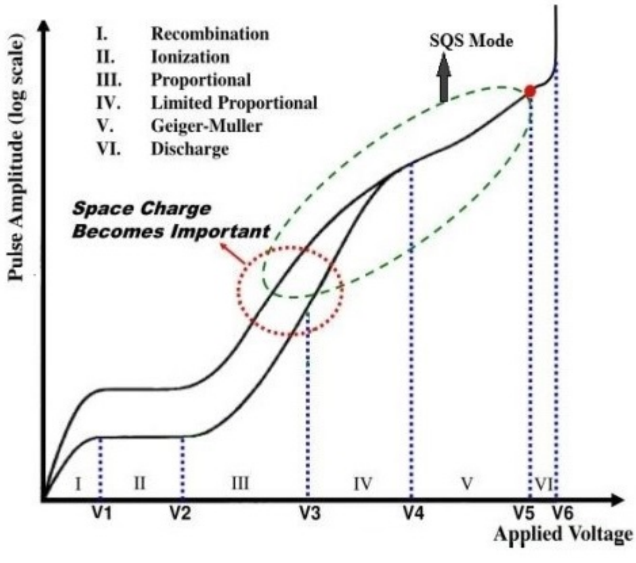

Figure 1: Detector performance mode curves versus applied voltage (Sauli, 1997).

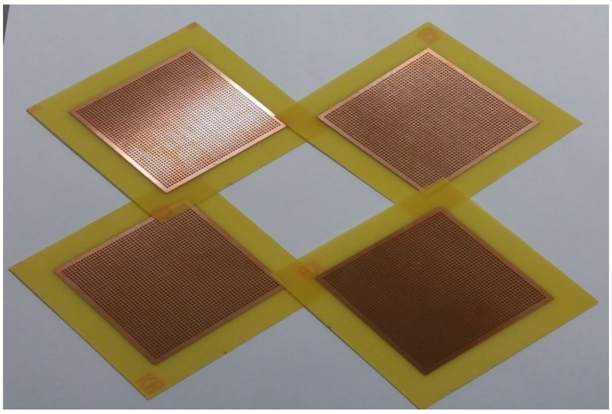

Figure 2: Thick gas electron multiplier used in the current work.

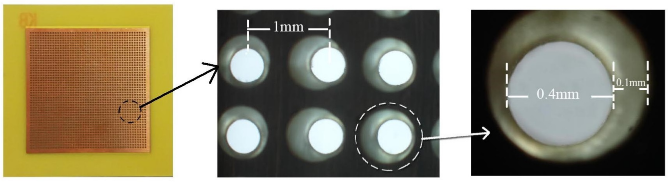

Figure 3: Microscopic structure of thick gaseous electron multiplier.

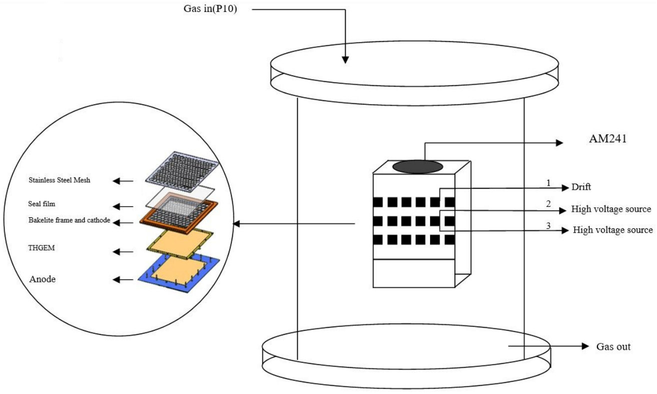

Figure 4: Sketch of measurement setup.

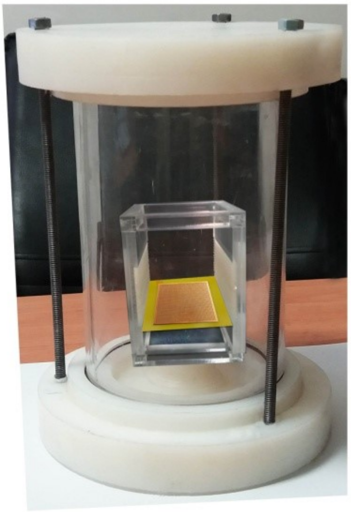

Figure 5: The measurement setup.

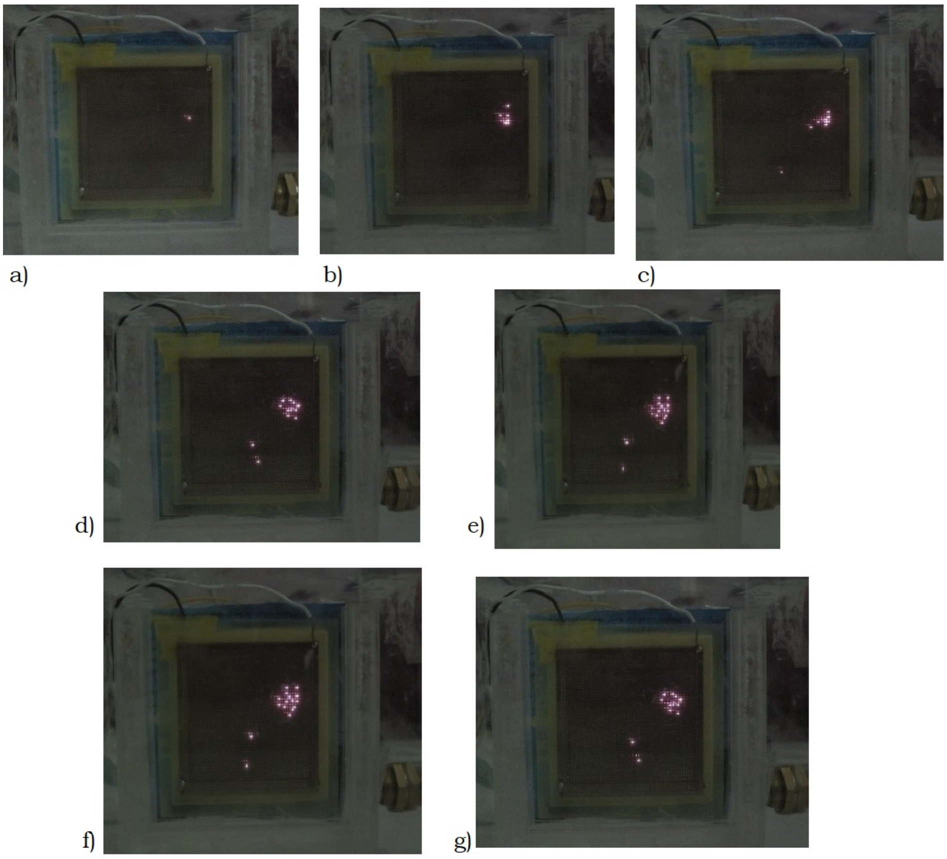

Figure 6: Images obtained for different operating voltages: a) 5200, b) 5400, c) 5600, d) 5800, e) 6000, f) 6200, and g) 6400 volts.

One of the main components of the designed system is a netted metal plate that is responsible for protecting the thin entrance plastic window with a surface density of less than 1.5 mg.cm^2. Herein, the window allows the passage of alpha particles. The third component consisted of an FR4 layer with a thickness of 0.4 mm that a 0.35-mm thickness copper layer with holes of 0.4 mm in diameter and 1 mm distance is placed on one side of it. This layer plays a role of a collector for the incoming alpha particles, and the copper layer is used as the cathode. Although the latter layer may reduce the entrance radiation to the detector (due to the collision of alpha particles with the collector), the accuracy of the contamination positioning will be increased. However, to compensate for the lost alpha particles and reaching to Raether's limit, it is necessary to increase the detector amplification factor according to Eq. (1). The fourth layer is a thick electron multiplier sheet that is responsible for replicating the electrons received from the pulse region. If the required condition is met for Raethers conditions inside each hole in the electron multiplier plate, the self-organizing light beams appear in a hole like a luminous pixel.

Here, the produced light is easily visible. The copper layer at the bottom of the electron multiplier plate also behaves as an anode (Fig. 4). In this experiment, two Am-241 alpha sources with 150 and 33 kBq activities have been used as strong and weak sources, respectively. The gaseous mixture used in this measurement consists of 90% argon and 10% methane (P10 gas) which enters the inlet chamber and exits from the outlet. The methane gas prevents the emission of UV radiation produced in the electron multiplication region and causes that the detector enters to the SQS operational mode.

4 Results and discussion

With applying the Am-241 sources (150 and 33 kBq activities) in front of the input window, no beam lights were observed in the holes which are considered as image pixels at voltages less than 5200 volts. When the voltage reached 5200 volts, as shown in Fig. 6-a, the light beam columns appeared in the holes just in front of the stronger source.

As can be seen in Fig. 6-b, by an increase in the voltage to 5400 volts, the light intensity, as well as the number of holes in front of the stronger source, have been increased. However, the pixels in front of the weaker source have not been illuminated yet. As the voltage increases to 5600 volts (see Fig. 6-c), the light intensity was increased in front of a stronger source, and also the light columns appeared in the holes in front of the weaker source. As the voltage increases further, both the light intensity and the number of holes in which the light columns observed were increased significantly (Figs. 6-d, Fig. 6-e, Fig. 6-f, and Fig. 6-g).

5 Concluding remarks

The obtained results show that the proposed system can be successfully used in monitoring surface contamination. This cost-effective system can be easily constructed and developed even in dimensions of several meters. As can be observed in Fig. 6, by increasing the operating voltage, the pixels (i.e., holes) just in front of the stronger source (standing for more contamination) are brighter. Moreover, the intensity of the generated light increases with an increase in the source activity. Therefore, the identification of the areas with very high levels of contamination becomes more convenient.

The main parameters affecting the positioning accuracy are the number of holes created per unit area of the thick electron multiplier and also the collector. Besides, the light scattering in front of the alpha source can be attributed to the low thickness of the collector. Clearly, applying a thicker collector can eliminate the scattering and consequently improves the image quality. In the same direction, the collecting and multiplier holes can be also led to improper functioning and reduce positional accuracy.

Since, the decay phenomenon and the initial ionization due to the entrance of radiation as well as the angular distribution of the incoming beams are statistically significant, in a few cases (seen in the images), a hole may be bright at a lower voltage and no longer glow at higher voltages. This can be prevented by integrating the light intensity created in a period of time.

The use of SQS mode was introduced a few decades ago to determine the location of the input beam in gaseous detectors. However, restrictions in controlling the spatial propagation of the light beam made it impossible to determine the location of the beams by a few millimeters of precision. But, in gaseous-electron multipliers which have been introduced in recent years, the expansion of the light column produced in SQS mode will be limited to the height of the holes. So, depending on the size of the hole, a precision of less than a few millimeters can be achieved.

In this study, the idea of the usage of gaseous multiplier detectors in SQS mode was developed to fabrication an alpha surface contamination monitor with a simple and low-cost system. Finally, with no need to signal reading, image processing, and complicated hardware and software, a two-dimensional image of the contaminated surface was reconstructed.

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