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A simulation study on angular and micro pattern effects in GEM detectors

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HIGHLIGHTS

- A useful approach for thermal neutrons detection is reported.
- The technique is based on the angular and micro pattern effects.
- Both of such methods were applied to GEM detectors.
- Simulation measurements were done via FLUKA MC code.

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ABSTRACT

A useful approach for the enhancement of thermal neutrons detection has been reported here. This technique, based on the angular and micro pattern effects, has been developed and applied to the boron-coated (^{10}B) Gas Electron multiplier (GEM) detector. In the angular effect case, as a general rule, the detector device is turned at an angle which improves the device response per unit area of the detector. While for the latter case, a regular pattern in the form of micrometer deep grooves is fabricated onto the converter coating, consequently it enhances the capture probability of the detector. For the current study, both of these techniques using a ^{10}B-coated GEM detector have been simulated for low energy neutrons. For the evaluation of detector response thermal neutrons in the energy ranges from 25 meV to 100 meV were transported onto the detector surface. For this work, FLUKA MC code has been utilized. The output in both cases has been estimated as a function of incident thermal neutron energies. By employing both techniques, the angle and the micro pattern dependent efficiencies for ^{10}B-coated GEM detectors are presented, which indicate an improved efficiency response of the device. We anticipate that by using these modifications can lead a further forward step in the development and improvement of thermal neutron detection technology.

1. Introduction

The fabrication of highly efficient neutron detectors has attracted much a great attention due to their various possible applications in material science, health physics, radiation detection, and many other fields of research. In many cases the detectors size is a limiting factor role for the applications (Solomon et al., 2007). This situation allows the research field community to intensely investigate neutron detectors to bring further improvement in their design and efficiency, which makes this an area of research of much interest.

Neutrons are neutral particles that can only be detected via their interaction with the detector material or through the production of secondary particles. In general, two commonly employed neutrons interactions are the $^{10}B(n,\alpha)\,^{7}Li$ reaction and the $^{6}Li(n,\alpha)\,^{3}H$ reaction, which are used for thermal neutron detection. Here previous reaction the $^{10}B(n,\alpha)\,^{7}Li$ leads to the reaction products given below (Convert, 1964; Convert and Forsyth; 1983, Tsoulfanidis, 1995, Knoll, 2000 and McGregor et al., 2003):

$$^{10}B + {}^{1}_{0}n \rightarrow \begin{cases} ^{7}Li^{*}, \ (\text{at } 1.015\,\text{MeV}) + \alpha \ (\text{at } 1.777\,\text{MeV}) \\ \text{ReactionQ} - \text{Value} = 2.792\text{MeV} \ (\text{to ground state}), \\ ^{7}Li^{*}, \ (\text{at } 1.015\,\text{MeV}) + \alpha \ (\text{at } 1.777\,\text{MeV}) \\ \text{ReactionQ} - \text{Value} = 2.310\text{MeV} \ (\text{1st excited state}) \end{cases} \quad (1)$$

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In this reaction products are released in opposite directions and the thermal neutrons (0.0259 eV) are absorbed by ^{10}B. Upon such absorption, 94% of the reactions leave the ^7Li ion in its first excited state, which promptly de-excites to the ground state ($\sim 10^{-13}$ s) by means of releasing a 480 keV gamma ray (McGregor et al., 2003). On the other hand, the remaining 6% of the reactions (in the form of the ^7Li ion) moves directly to its ground state. In this reaction, the microscopic thermal neutron absorption cross-section is 3840 b. Furthermore, the microscopic thermal neutron absorption cross-section decreases with increasing neutron energy, which indicates thermal neutron absorption cross-section's dependence proportional to the inverse of the neutron velocity ($1/\upsilon$) over larger energy ranges (McGregor et al., 2003; Garber and Kinsey, 1976; McLane et al., 1988).

In this article, a suitable approach based on the angular and micro-pattern effects is presented, to improve the efficiency of Gas Electron Multiplier (GEM) detectors (Sauli, 1997). The neutron detector configuration discussed in the present work consists of a ^{10}B converter material attached onto the GEM surface, employed for thermal neutron detection. Previous studies performed with the neutron semiconductor detectors have shown that the angular dependence can efficiently improve neutron detection efficiency (Ranjbar Kohan et al., 2012). In the present simulation study, we have used a GEM detector for thermal neutron detection and both the angular and micro pattern dependence on the detection efficiency have been evaluated.

In particular the efficiency for thermal neutron detection has been estimated by using the latest version of Fluka-2011.2.17 (Battistoni et al., 2007; Fasso et al., 2005; Ferrari et al., 2011) software package with its low energy neutron physics running on our PC work station.

2. The basic idea of neutron detection

2.1. Angular effects on detection

In order to find the detector angle effects on detector response, we adopted a useful approach proposed by McGregor et al. (2003), which has been employed for thermal neutron detection using a semi-conductor detector. According to this technique the detector device can be turned at different angles, which accordingly enhances the thermal neutron detection efficiency per unit area for neutrons that arrive from one direction (McGregor et al., 2003).

In such analysis, it is proposed that the device has infinite dimensions in the Z (lay into to the page) and Y directions. By such means edge effects are excluded. Upon employing the mentioned technique (McGregor et al., 2003), the detector device can be rotated with keeping the angle θ from 0° to 90° with regard to the direction of the impinging neutrons. Here the detector at 0° is considered orthogonal to the neutron beam and 90° refers as parallel to the neutron beam (can be referred to (McGregor et al., 2003, Fig. 19). Additionally, the effective neutron absorbing film thickness can be enhanced with increasing angle, while keeping the charged particle transit distance as fixed to reach the detector interface. By this way, particularly, the neutron absorption efficiency of the detector can be increased upon keeping the same minimum detectable solid angle. For the each charged-particle-reaction product, the neutron detection efficiency can be expressed by (McGregor et al., 2003):

$$S_P(D_F) = 0.5F_P\left\{\left(1+\frac{\cos\theta}{\Sigma_F L}\right)\left(1-e^{-\frac{\Sigma_F D_F}{\cos\theta}}\right)-\frac{D_F}{L}\right\} \text{ for } D_F \le L$$

$$S_P(D_F) = 0.5F_P e^{-\Sigma_F(D_F-L)/\cos\theta}\left\{\left(1+\frac{\cos\theta}{\Sigma_F L}\right)\left(1-e^{-\frac{\Sigma_F D_F}{\cos\theta}}\right)-1\right\} \text{ for } D_F > L \quad (2)$$

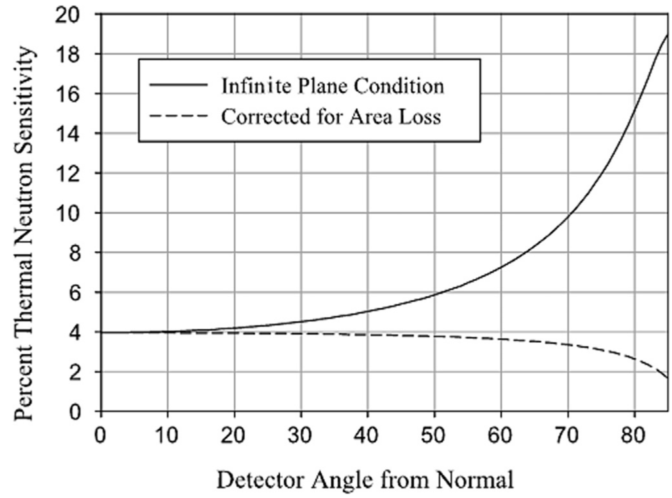

Fig. 1. A view of the thermal neutron detection efficiency dependence on the detector's angle. Note that the efficiency diminishes at source to detector angle greater than 60°. [The figure adopted from Ref. McGregor et al. (2003) with permission].

The parameter D_F stands for the actual converter film thickness, S stands for the surface, L is the effective reaction product range, F_P is the branching ratio of the reaction product, $S_p(D_F)$, is the sensitivity for a single reaction product as a function of the film thickness, D_F.

Fig. 1 (McGregor et al., 2003) reports a comparison of the calculated sensitivities for a ^{10}B-coated device as a function of angle. A quick look to this figure describes the dramatically efficiency increases at angles greater than 45°. However this does not specify an evident about the disruptive behavior at 45°, in fact the efficiency increases smoothly, with some exponential dependence.

According to Ref. (McGregor et al., 2003), the results would indicate that turning the device such that the intersection angle is almost 90° would allow very high efficiencies, yet the result is a consequence of the infinite plane assumption. This method further suggested that for small devices, the actual neutron detection efficiency will be significantly less due to both the “effective sensitive area” decreasing in size and charged particle end effect losses (McGregor et al., 2003).

Upon considering such possibilities, we have proposed a method, based on the incident angle dependence effect on the detection device. A similar technique has been reported and adopted by Piscitelli and Van Esch (2013). A detail description of this strategy can be seen in Fig. 2. In this scheme, neutron beams are incident on the detector surface. The first incident neutron beam (L_{max}) which falls on the detector surface perpendicularly while the second neutron beam (L'_{max}) falls on the detector via making a slight angle (θ). The geometrical configuration demonstrates that the neutron beam L'_{max} has to cover more distance while reaching the detector surface, and as a result by following this larger path, a higher interaction rate occurs.

Generally, with the change in detector's angle, the incident neutrons cross-sectional area also increases. However, the increase of cross-sectional area does not always mean that the detector's efficiency will increase as well. This is due to the fact, only the escape charged-particles from the converter surface of the detector have been counted for the efficiency evaluation. This situation is explained in Fig. 2, where upon the interaction of incident neutrons, the generated particles escape with the largest length known as L_{max} value, when the detector's angle changes. While after the interaction, particle escape length is known as L'_{max}