THE EFFECT OF THE LiF FILM TOPOLOGY ON DETECTION PROPERTIES OF THERMAL NEUTRON SEMICONDUCTOR DETECTORS

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1. Introduction

Variety of high quality semiconductor materials provides a broad range of their utilization as detectors for different kind of ionizing radiation. The choice of a detector material is usually subjected to specific application demands. Nowadays, materials like Si, SiC, GaAs and CdTe, are the most commonly employed to fabricate radiation detectors. In our recent research, we have focused our interest on GaAs- and SiC-based detectors. As far as GaAs-based detectors has proved advantageous due to relatively low costs, high reaction rates ensured by high mobility of charged carries ($\mu_{electrons} > 8000\ cm^2V^{-1}s^{-1}$ and $\mu_{holes} = 400\ cm^2V^{-1}s^{-1}$ at room temperature) and effectiveness for X-ray and gamma-ray detection due to relatively high atomic number of Ga and As; SiC-based detectors looks perspective mainly due to high breakdown voltage of about 2×10^6 V/m and very high radiation hardness and temperature resistance resulting from strong bonds between Si and C atoms in SiC crystal and from wide bandgap (3.26 eV at room temperature).

Regardless of the choice of the semiconductor material, registration of fast or thermal neutrons requires additional medium serving as a converter of neutral particles to easily detectable, usually charge-carrying particles. In the case of thermal neutrons, the conversion layer of ^{6}LiF is often used to produce via nuclear reactions alpha particles and tritons, which can be detected with high probability [1, 2].

In our recent paper, we have performed some calculations using MCNPX code to predict an optimal thickness of a ^{6}LiF converter and to simulate a detector response to thermal neutrons [3]. In the model used in the simulations, a homogeneous layer of ^{6}LiF was assumed. According to our experience, the practical process of ^{6}LiF film deposition may result in production of inhomogeneous, porous conversion layer; whereby, an accuracy of its thickness determination remains questionable. Furthermore, the spatial homogeneity of the layer can be affected by its powder-like nature. The goal of this paper is to quantify numerically how the topology of the deposited ^{6}LiF film can affect the resultant detector response. To this purpose, the simulations using MCNPX code were carried out.

2. Function of the ^{6}LiF film in detection process, its properties and preparation

There are many materials, which can satisfyingly facilitate registration of thermal neutrons, like ^{10}B, ^{6}Li, LiH, ^{157}Gd, Li_3N, Li_2C_2, Li_2O, ^{235}U or $Zr^{10}B_2$ [4]. The ^{6}LiF is often used as converter due to high thermal neutron absorption cross-section (σ = 942 b at a neutron energy of 0.0253 eV), relatively high energies of reaction products and acceptable chemical properties.

The neutron capture reaction on ^6Li results in alpha and triton particle production as follows:

$^6Li + n \rightarrow \alpha$ (2.05 MeV) + ^3H (2.73 MeV) Q = 4.78 MeV

The reaction products from the thermal neutron capture are released in opposite directions, as illustrated in Fig. 1, and therefore, the simple planar detector can register either alpha or triton particle, but never both.

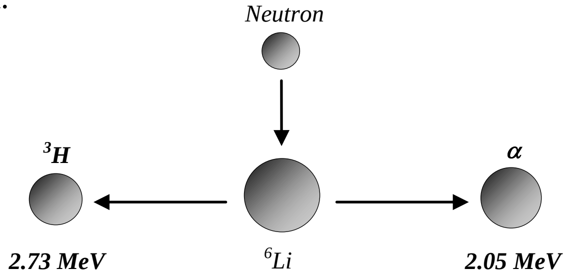

Fig.1: *Nuclear reaction products released by a thermal neutron interacting with ^6Li atom.*

Fig. 2 shows the Bragg ionization distributions for the 2.73 MeV - tritons and for the 2.05 MeV - alpha particles in ^6LiF calculated using SRIM program [5]. As obvious, the average range of the heavier alpha particles passing through ^6LiF converter is remarkably lower, as compared to lighter tritons; i.e. 6.05 and 33.49 μm, respectively. Due to neutron absorption in a region too far away from the ^6LiF-detector boundary, where the energy of created reaction products is not sufficient to reach the sensitive volume of a detector, one can expect existence of an optimal ^6LiF layer thickness, which will result in highest detection efficiency (optimal thickness of 25 μm was reported in [3]). The highest energies of produced reaction products are low enough for both of them to be fully absorbed in the GaAs/SiC detector depleted region (the ranges of 2.73 MeV -tritons and 2.05 MeV - alpha particles are 31.77 μm and 6.06 μm in GaAs and 39.19 μm and 6.84 μm in SiC, respectively).

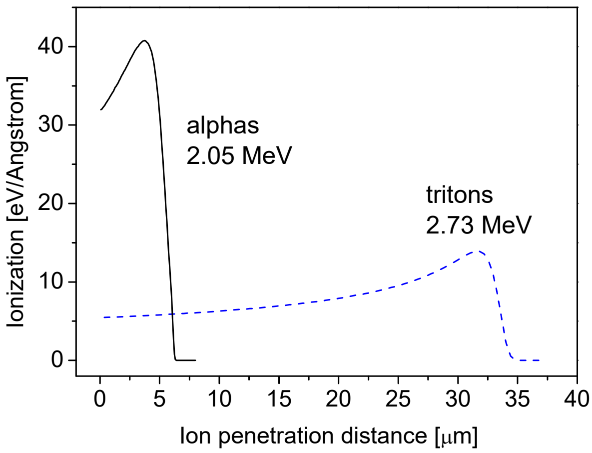

Fig.2: *The Bragg curves for2.73 MeV tritons and for 2.05 MeV alpha particles in ^6LiF.*

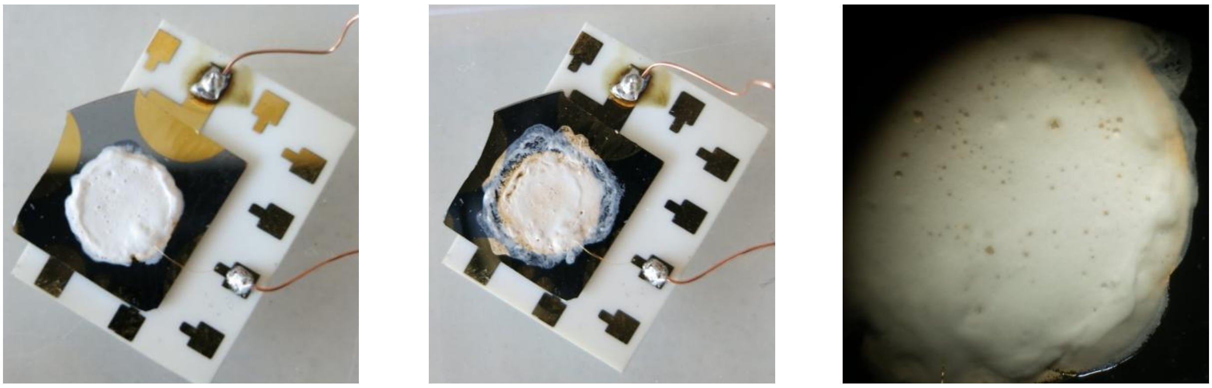

Fig.3: *^6LiF conversion layer applied on a detector and its image from a microscope.*

Conversion films have been prepared from a ^{6}LiF powder (enriched in ^{6}Li isotope to 95 %) mixed with distilled water and a glue solvent and deposited using a micropipette on the top contact of a GaAs and SiC detector. Fig. 3 shows that the achievable uniformity of the film varied and the microscope inspection revealed its porous structure, especially when deposited in thinner layers. The thickness of the deposited films varied between 5 and 50 μm (recalculated roughly from a ^{6}LiF mass density of 2.54 g/cm^3).

3. Calculation details

To calculate a detector response to thermal neutrons, the version 2.7.0 of the MCNPX code [6] has been used. MCNPX is a calculation code based on Monte Carlo algorithms, which enables to follow the transport of neutrons and also products from neutron interactions like alpha particles and tritons, whereby the nuclear data tables along the model physics are employed.

A detector has been modelled as with GaAs filled cylinder of a diameter of 6 mm having a thickness of 59 μm corresponding to an applied reverse bias of ca 50 V in a real experiment. On its top side, the layers of Ti, Pt and Au of thicknesses of 10, 30 and 90 nm representing Schottky contact were placed followed by the topmost layer of ^{6}LiF constituting the conversion film positioned between the source and the front detector contact. A ^{6}LiF conversion layer was modelled firstly as a homogeneous film of different thicknesses (varied from 5 to 50 μm) and secondly, as a film composed of small balls with 5 μm diameter arranged in layers according picture in Fig. 4, representing powder-like structure of the ^{6}LiF converter. The space between balls was filled with air, whereby its volume was equal to the volume occupied by the balls. A disk source emitting thermal neutrons perpendicularly has been placed at a distance of 3 cm from the detection structure. The outside medium was air.

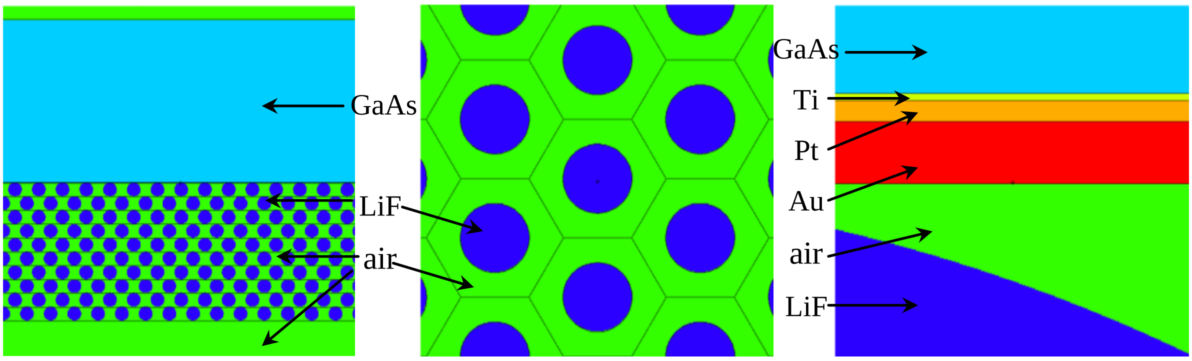

Fig.4: *MCNPX model of a detector structure with powder-like ^{6}LiF conversion film, (a) front view of a GaAs detector-contacts-^{6}LiF-structure, (b) cross-section through ^{6}LiF layer, (c) detailed front view of the Ti-Pt-Au Schottky contact area.*

To simulate a detector response to thermal neutrons, the F8 tally has been employed, which is a pulse height tally and provides the energy distribution of pulses created in a cell that models the physical detector. A special tally treatment function GEB (Gaussian Energy Broadening) has been applied to F8 tallies to take into account the observed energy broadening of the physical radiation detector of ca 300 keV.

4. Results

Fig. 5 shows detector response calculated using F8 tally in the MCNPX code for GaAs detector covered by a homogeneous ^{6}LiF film of different thicknesses (a) and by a ^{6}LiF film having a powder-like structure (b). For comparison, 2 layers of the ^{6}LiF balls in

Fig. 5 (b) correspond in term of volume to the 5 μm thick ^{6}LiF layer in Fig. 5 (a), 4 layers to 10 μm, etc., and the respective responses have therefore the same colour in the figure. Depicted spectra include responses from charged reaction products, i.e. from tritons and alpha particles. The contribution from tritons manifests as a dominant peak positioned at the energy of about 2.75 MeV, as expected due to the presence of the most energetic tritons created in the vicinity of the ^{6}LiF-detector interface. Analogously, the contribution from produced alpha particles to the total response is shifted to lower energies of about 2 MeV. Its lower amplitude is caused by the fact that the energy carried by alpha particles is deposited during interactions in less steps as compared to lighter tritons. With increasing thickness of the ^{6}LiF film, the contribution from tritons is getting broader and predominates in the pulse height tally. The total response height apparently tends to decrease for ^{6}LiF thicknesses higher than its optimal value (from 30 μm down).

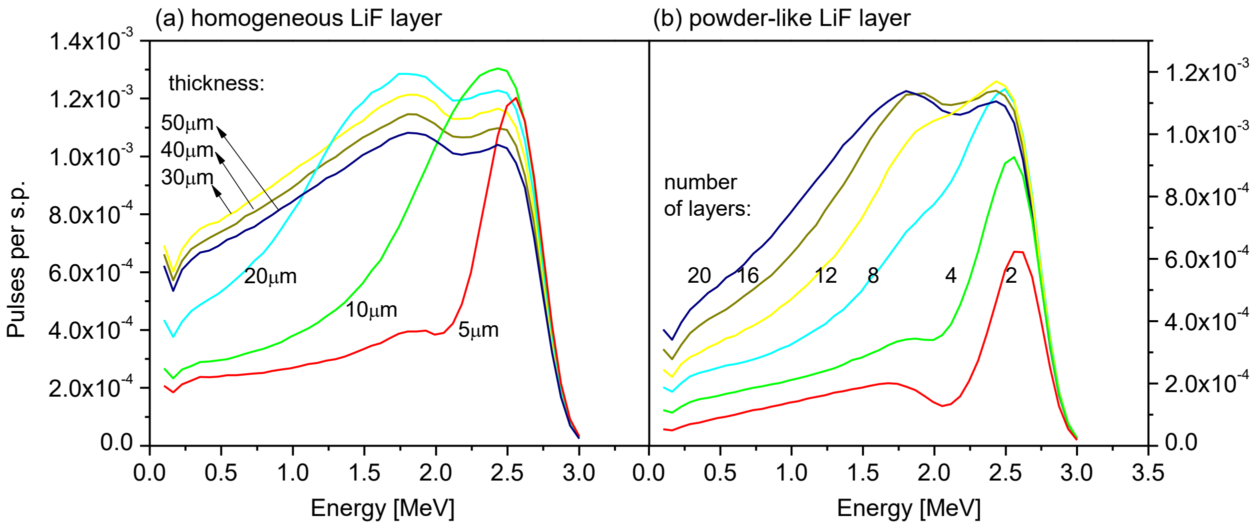

Fig.5: *GaAs detector response to thermal neutrons calculated using MCNPX code; detector covered by a ^{6}LiF conversion layer of homogeneous structure (a) and of powder-like structure (b).*

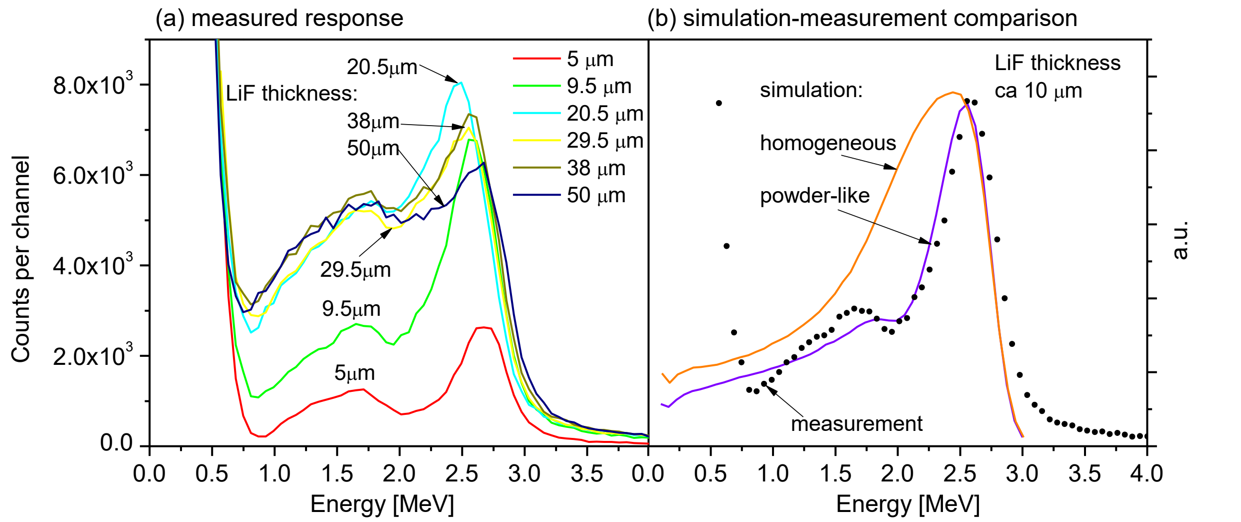

Fig.6: *Measured SI-GaAs detector response for different ^{6}LiF conversion layer thicknesses collected at an applied reverse bias of 50 V (a), comparison of detector response measured for 9.5 mm thick ^{6}LiF conversion layer with corresponding simulations assuming homogeneous and powder-like model of conversion layer (b).*

The responses collected in the real measurements using semi-insulating GaAs detector at a reverse bias voltage of 50 V are depicted in Fig. 6 (a). They show likewise two hills related to tritons and alpha particles and a noise peak in the low energy region. Fig. 6 (b) compares measured response of the 9.5 μm thick ^{6}LiF film with those simulated using both, homogeneous and powder-like models. Apparently, mainly for the lower ^{6}LiF film thicknesses, simulated response of the proposed powder-like model fits better the real data as compared to simulation results from the homogeneous layer of ^{6}LiF. The most visible discrepancy between measurement and simulation is in the region, where the alpha particles contribute to the total response. MCNPX simulations underestimate this part obviously. This tendency can result from the fact that the code uses physics models to transport the alpha particles created in the nuclear interactions, which might have limited accuracy in the inspected energy region.

5. Conclusion

Using MCNPX simulation code, the effect of topology and thickness of the ^{6}LiF conversion film on GaAs semiconductor detector response to thermal neutron has been studied. A powder-like MCNPX model of the conversion film has been proposed and has proved as a better fitting model to the measured data, especially for lower ^{6}LiF thicknesses.

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