GALLIUM ARSENIDE DETECTORS WITH ^{6}LiF LAYER FOR THERMAL NEUTRON DETECTION

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1. Introduction

Semiconductor detectors for neutron registration and application in neutron radiography have an increasing importance recently.As semiconductor material itself cannot be used for thermal neutron detection, some conversion material turning neutrons into detectable particles is necessary. There are few possible candidates for neutron conversion: ^{10}B, ^{6}Li, ^{6}LiF or Gd. Among them the compound ^{6}LiF seems to be the best choice. In comparison to pure ^{6}Li it does not suffer corrosion [1]. Gd converts neutrons to gamma rays [2, 3], which are difficult to distinguish from background gamma rays in a mixed radiation field which reduces its practical use. With^{10}B coating the detectors achieve lower thermal neutron detection efficiency than with ^{6}LiF coat as the range of products from^{10}B(n,α)^{7}Li is lower than the range of ^{6}Li(n,α)^{3}H productsin particular conversion material[1]. In our experiments we have coated our previously developed GaAs detectors [4-9] with ^{6}LiF layer to register thermal neutrons from ^{239}Pu-Be neutron source.

2. Experimental Details

Investigated detector structures were prepared from bulk VGF(Vertical Gradient Freeze) SI (semi-insulating) GaAs waferat the Institute of Electrical Engineering SAS in Piešťany. The thickness of the both side polished wafer was 350 μm, the resistivity $9.1\times10^7\Omega$cm and the electron hole mobility 6285 cm^2/Vs. The circle blocking Ti/Pt/Au Schottky contact, of 0.6cm diameter, was evaporated on the top side of GaAs wafer. A whole area quasi ohmic contact from Ni/AuGe/Au multilayer was formed on the opposite side of the wafer. The detector was glued with its ohmic contact to a ceramic holder by a silver paste and wire bonded to contacting pad. For thermal neutron detection^{6}LiF conversion layer was sprayed on the top Schottky contact by a technology described in [10]. Li was enriched by isotope^{6}Li to 95% in used ^{6}LiF powder. Following nuclear reaction was used to convert thermal neutrons to charged particles:

$$^6Li + n \rightarrow {}^4He(2.05MeV) + {}^3H(2.73MeV) \qquad (1)$$

The products of the nuclear reaction of neutrons in ^{6}LiF layer Eq. (1), the 2.05 MeV alpha particle and 2.73 MeV triton, were detected by SI GaAs detector. Their range in GaAs material is rather short, 5μm for alphas and about 30 μm in the case of tritons [11]. The range of products in conversion layer itself is 6.05μm for 2.05 MeV alphas and 33μm for 2.73 MeV tritons [12].In comparison to our previously developed SI GaAs detectors of thermal neutrons with ^{6}LiF layer [13] we used now larger area of detector to obtain better statistic during neutron registration and more sophisticated type of metallization.

Before and after the conversion layer deposition the current voltage characteristics of investigated detectors were measured (Fig. 1). It can be seen that the layer application has slightly increased the reverse current, by about 20nA at 200V, and decreased the detector breakdown voltage: from 340 V to 293 V. Such slight deterioration of electronic properties does not limit detector functionality.

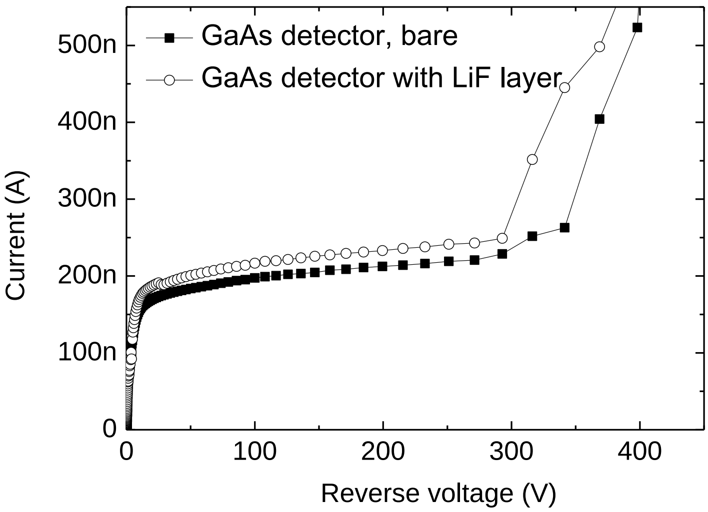

Fig.1: *Current-voltage characteristic of SI GaAs detector before (bare) and after the ^{6}LiF conversion layer application.*

3. Results and Discussion

Prior testing SI GaAs detector as a detector of thermal neutrons, the alpha particle calibration tests with bare detector were provided. Using ^{241}Am, a source of 5.48 MeV alpha particles, the optimal setting of spectrometric chain for registering the products of neutrons from conversion reaction Eq. (1) was chosen. The detector was connected to CANBERRA preamplifier and portable spectroscopy workstation based on digital signal processing InSpector 2000 with Genie2000 software.Fig. 2 shows ^{241}Am alpha spectrum measured by SI GaAs detector at various reverse bias voltages. As the voltage rises the peak shifts to higher channels thanks increasing charge collection efficiency of GaAs detector. At 250 V reverse bias voltage the SI GaAs detector registered 5.48 MeV alpha particles in channel 68 (Fig. 2). At identical setting of spectrometric chain, regarding signal gain and shaping time, the products of neutron conversion are expected to be registered in channel18 for alphas and channel 29 for tritons.

The response of thermal neutrons was measured using SI GaAs detector with ^{6}LiF conversion layer of different thicknesses: 36 μm and 71 μm, respectively. As a source of neutrons a ^{239}PuBe with fluency of 1.7×10^{7} neutrons per second into solid angle 4π was used. Measured spectra were compared to spectrum obtained using bare detector (Fig. 3a). A significant difference can be observed indicating thermal neutron detection. A spectrum measured by SI GaAs detector without conversion layer represents the gamma ray background present at the neutron source. Subtracting the gamma background from the spectra in Fig 3a, net contribution from neutrons was obtained depicted in Fig 3b, where two peaks can be observed: one representing registered alpha particles (^{4}He – channel 19) and one representing tritons (^{3}H – channel 31), both the products of neutrons interacting with ^{6}Li in ^{6}LiF conversion layer Eq. (1). We can observe that the thickness of conversion layer did not significantly affect detected counts. It is caused by the fact that used ^{6}LiF layer thicknesses (36 and 71 μm) are beyond the theoretical value with maximum thermal neutron detection efficiency (25 μm)[1, 12]. Growing higher thickness of conversion layer does not increase the detection efficiency due to low range of conversion products in layer itself.

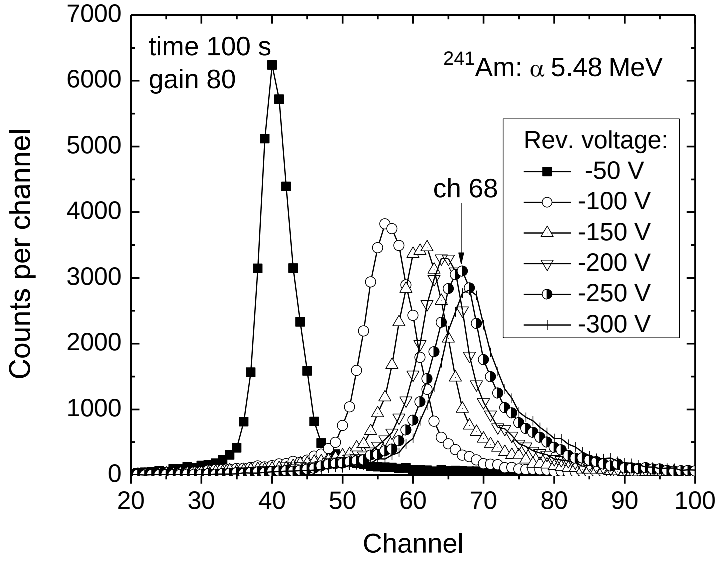

Fig.2: *Alpha spectrum of ^{241}Am measured by SI GaAs detector without conversion layer at different reverse bias voltages.*

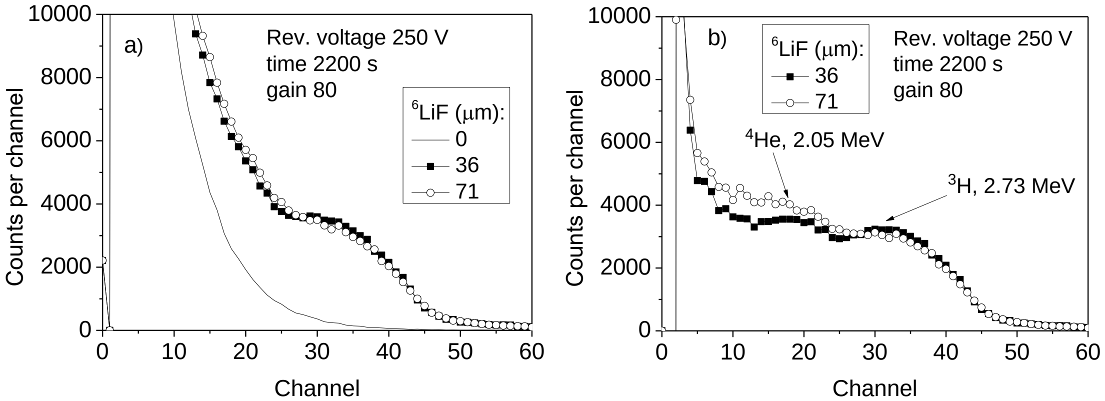

Fig.3: *a) Spectra measured by SI GaAs detector with or without ^{6}LiF layer irradiated by thermal neutrons from ^{239}PuBe source.*
b) Net counts (without gamma background) from GaAs detector with different thickness of ^{6}LiF converter layers irradiated by ^{239}PuBe neutron source.

Considering the position of peaks in Fig. 3b, we made the calibration curve including the results from alpha particle measurements (Fig. 2) at the same reverse bias voltage (-250 V).Obtained calibration curve (Fig. 4) shows nice linearity (standard deviation less than 1%), confirming the registration of products of thermal neutrons in^{6}LiF layer by the SI GaAs detector.

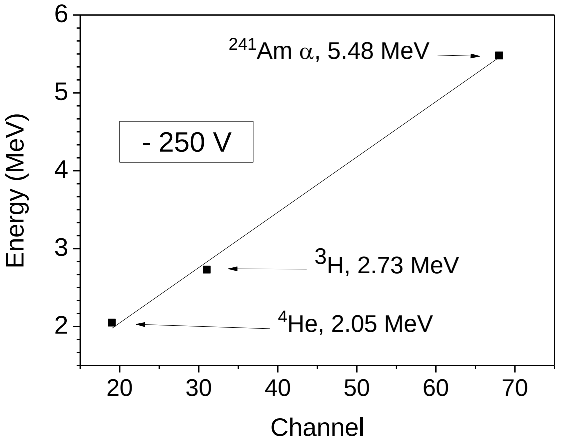

Fig.4: *The calibration curve obtained by SI GaAs detector registering 5.48 MeV alpha particles and products of neutrons in ^{6}LiF layer, the 2.05 MeV alpha particles and 2.73 MeV tritons.*

4. Conclusion

We have successfully modified our previously developed SI GaAs detectors with ^{6}LiF layer to register thermal neutrons from ^{239}Pu-Be neutron source. Measured current-voltage characteristics of detectors confirmed only slight deterioration of electronic properties after layer deposition. The measured spectra of thermal neutrons showed the evidence of ^{6}Li(n,α)^{3}H nuclear reaction in conversion layer. It was proved by energetic calibration of detector with ^{241}Am alpha source, showing very good linearity of calibration curve.

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