DETECTION OF FAST NEUTRONS USING SEMI-INSULATING GaAs COATED BY HIGH DENSITY POLYETHYLENE

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1. Introduction

Neutron transmission imaging or tomography has potentially vast usage in various areas of industry. Petrology, archaeology, geology, automotive and aviation industry, mining, detection of drugs and explosives can utilize neutron imaging. High neutron cross-section of hydrogen results in a good contrast for water or organic fluids. Also monitoring of fast neutron emission in hot plasmas is very important at present [1]. Development of a good detector of fast neutrons is a challenging task. Detectors based on semi-insulating (SI) GaAs are very perspective due to their good radiation hardness and detection performance for high energy charged particles and also X- and gamma-rays [2–4].

In this paper we continue our study of fast neutron detection with optimized parameters of semiconductor detector [5].

2. Detectors fabrication

Detectors have been fabricated from bulk VGF (Vertical Gradient Freeze) SI GaAs material (producer: CMK Ltd., Žarnovica). Used base material has the resistivity about 10^7 Ωcm and the Hall mobility more than 6500 cm^2/Vs at room temperature corresponding to the detector-grade material requirements [6]. The SI GaAs wafer with (100) crystallographic orientation was polished by the producer from both sides to (220±10) µm. Square shaped

Schottky electrodes of AuZn (120 nm) metallization of 2.50 mm size using photolithography masking onto one side (top) of the wafer were evaporated. Just before evaporation the surface oxides were removed by washing in a solution of $HCl:H_2O$ = 1:1 at room temperature (RT: ~300 K) for 30 sec. The whole area quasi-ohmic electrode was formed by AuGeNi/Au (50/70 nm) on the backside of the sample. The metal contacts were evaporated in a dry high-vacuum system. Finally, the wafer fragment was cleaved onto individual detector chips.

3. Principle of fast neutron detection

As a source of fast neutrons the radionuclide ^{239}Pu-Be was used in our experiment. The neutrons are produced by the following exothermic nuclear reaction in the source:

$$ {}^{4}_{2}He + {}^{9}_{4}Be \rightarrow {}^{1}_{0}n + {}^{12}_{6}C + 5.71\,MeV, \tag{1}$$

where the interacting alfa-particle is released by ^{239}Pu nucleus. Energy spectrum of neutrons is continuous (0.5 - 12 MeV) with two local maxima at 3.5 and 7 MeV, where first maximum is about two times higher.

As the detector based on GaAs does not interact directly with fast neutrons we need so-called conversion layer, which transforms energy of neutron to a charged particle, which is simply detectable. In our case we used HDPE (High Density PolyEthylene) containing high amount of hydrogen, which tends to have relatively high elastic scattering cross-sections for fast neutrons and often (n, p) reactions occur. Schematic view of the fast neutron detection is showed in Fig. 1.

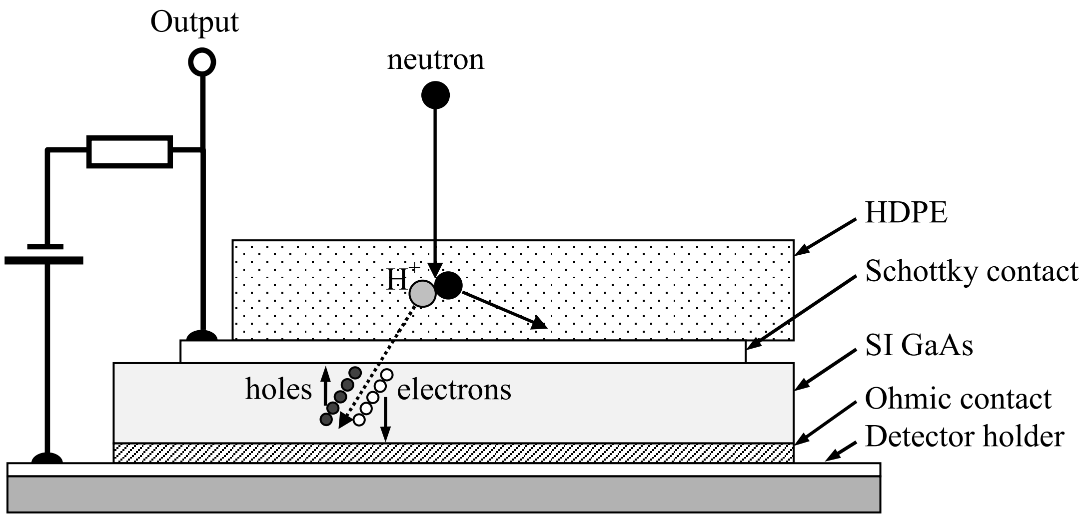

Fig.1: *Schematic view of the fast neutron SI GaAs detector and principle of its operation.*

Neutrons interact with hydrogen atoms of conversion layer. The energy of neutron is transformed through the elastic collision to the proton which continues with high probability to the semiconductor material. Electrons (e^-) and holes (h^+) are created in the volume of detector during slowing-down of proton. The high bias voltage between detector electrodes separates generated e^- - h^+ pairs and the electric signal can be measured at the output.

4. Results and discussion

The thickness of conversion layer influences probability of neutron scattering. For better detection efficiency we need thicker conversion layer with an optimized, rather higher thickness, but slowing-down of scattered protons in thicker conversion layer reduces the output detector signal. Due to this the thickness of conversion layer has to be matched to the energy region of detected neutrons.

In our experiment, we used HDPE layers of two different thicknesses, i.e. 170 and 480 μm. The range of scattered protons for the most probably energy of 3.5 MeV (considering characteristics of used ^{239}Pu-Be fast neutron source) is about 182 μm. Such protons are able to deliver its total energy to SI GaAs detector with minimum thickness of about 75 μm. The fabricated neutron detector was connected to the charge-sensitive preamplifier based on CREMAT CR-110, shaping amplifier ORTEC 572, analog-to-digital converter ADC ORTEC and multichannel analyzer M2D controlled by PC. The pulse height spectrum measured by the fabricated neutron detector is shown in Fig. 2.

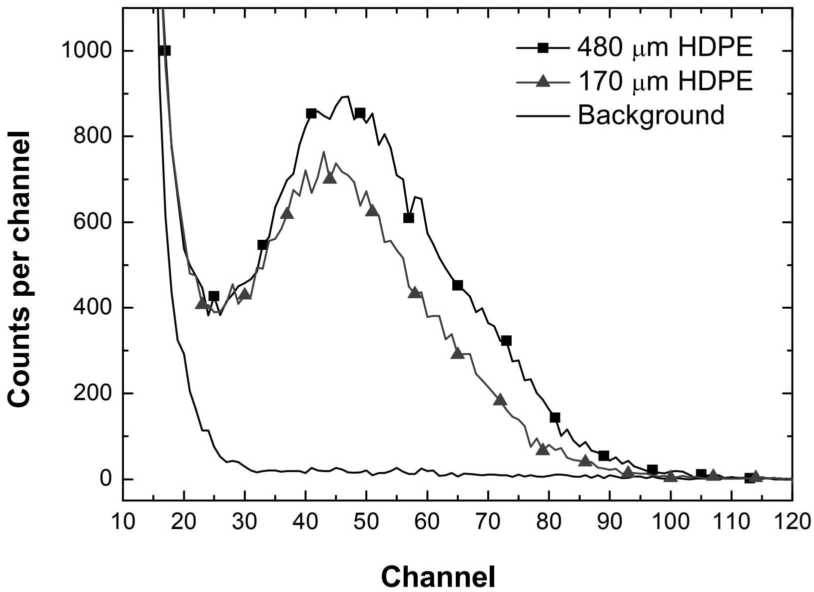

Fig.2: *Measured pulse height spectra of fast neutrons generated by the ^{239}Pu-Be radioisotope.*

The background measurement was performed with the detector turned backwards (the conversion layer was placed behind the detector; scattered protons were not able to reach the active zone of the detector). The directional sensitivity of conversion layer is clearly visible. The difference between the spectra measured with conversion layers of different thicknesses demonstrates that thicker HDPE is more efficient for higher energy of neutrons (channels 35 and higher), which is in accordance with our expectations.

5. Conclusions

We fabricated semiconductor detector of fast neutrons with HDPE conversion layer. The detector size was defined by square Schottky contact with 6.25 mm^2. In the experiment we used two different thicknesses (170 and 480 μm) of the HDPE conversion layer. Fast neutrons with energies between 0.5 and 12 MeV were detected. The thicker conversion layer gives higher detection efficiency for energetic neutrons and confirms our consideration. Following optimization of the detector and conversion layer thickness is in progress.

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