

CHARACTERIZATION OF A PORTABLE THERMAL NEUTRON DETECTOR

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ABSTRACT

A portable thermal neutron detector prototype, using a PIN-type silicon photodiode coupled to a boron converter, was developed at the Nuclear and Energy Research Institute (IPEN-CNEN/SP). Several boron layers were made by Pulsed Laser Deposition method and two different prototypes were made using distinct approaches in the associated electronics. The prototypes were characterized by measurements with the cold neutron beam at PHADES (Polarized ^3He and Detector Experiment Station), in the NIST Center for Neutron Research. The distance between the prototype and the neutron source was different for each prototype: 70 cm (prototype one) and 7 cm (prototype two). The linearity behavior was verified for both prototypes in order to verify the relationship between counts and neutron fluence. The intrinsic efficiency values obtained for prototypes one and two were, respectively, $(1.78 \pm 0.01)\%$ and $(5.2 \pm 0.4)\%$. The angular dependence was verified only for prototype one. The concept of this detector can be applied in a future dosimeter project.

1. INTRODUCTION

Since the ^3He crisis, there is an increasing demand for neutron detectors using different types of converter materials, as ^{10}B or compounds containing ^{10}B [1], for instance converter materials can be applied as coating, such as those used in B-coated diodes or in B-lined proportional counters. ^{10}B has a relatively high thermal neutron absorption cross-section [1] comparing with other materials, short reaction product ranges (α , Li), a microscopic thermal neutron (0.0259 eV) absorption cross-section of 3840 barns and also a high natural abundance (20%) which makes it a particularly attractive candidate as an alternative converter.

The thermal neutron detection process based on a boron layer coupled to a semiconductor detector is an interesting possibility. The detection initially occurs by neutron absorption [2] in the converter material producing ionizing particles (α , Li) in opposite directions. These particles should reach the semiconductor volume, lose energy mainly by Coulomb scattering producing electron-hole pairs, as shown in Fig. 1. These pairs can be multiplied and collected in semiconductor contacts by applying a bias voltage, as induced charge produces an image charge in contact that is integrated and measured by an external preamplifier and accompanying electronics (e.g., an MCA analyzer or digital counter).

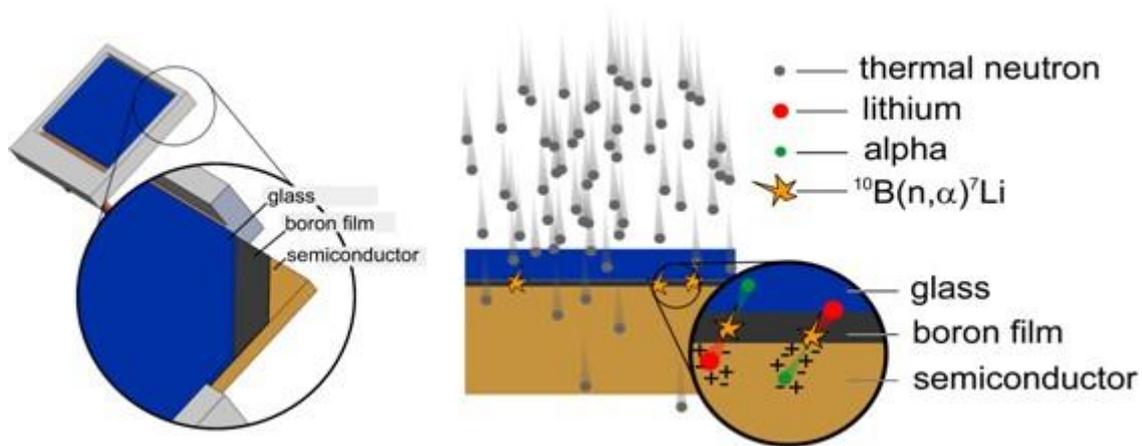


Figure 1: Schematic illustration of neutron detection process in a semiconductor.

In this paper, a portable thermal neutron detector prototype using a PIN-type silicon photodiode coupled to a boron converter was developed at Nuclear and Energy Research Institute (IPEN-CNEN/SP). The boron layers were made by Pulsed Laser Deposition method (PLD). The prototypes were characterized using the cold neutron beam in PHADES (Polarized ^3He and Detector Experiment Station) at the NIST Center for Neutron Research. In this study, the intrinsic efficiency value was obtained for two prototypes, in order to evaluate the best configuration of the associated electronics.

2. MATERIALS AND METHODS

2.1. Thermal neutron detector prototype

The thermal neutron detector prototype is composed of an unsealed Si photodiode (Fig. 2), without the epoxy resin layer to avoid the alpha particles absorption. This type of semiconductor detector has attractive features, as working properly at room temperature and the small size, allowing application in portable devices. The photodiode was coupled to a boron layer (Fig. 2) made by PLD using a femtosecond pulsed laser system [3]. The material was deposited on the surface of glass slide substrates (10 mm \times 10 mm), that have the same dimension of the active area of the photodiode, and the boron layers were produced with the same thickness, $(2.4 \pm 0.3) \mu\text{m}$.

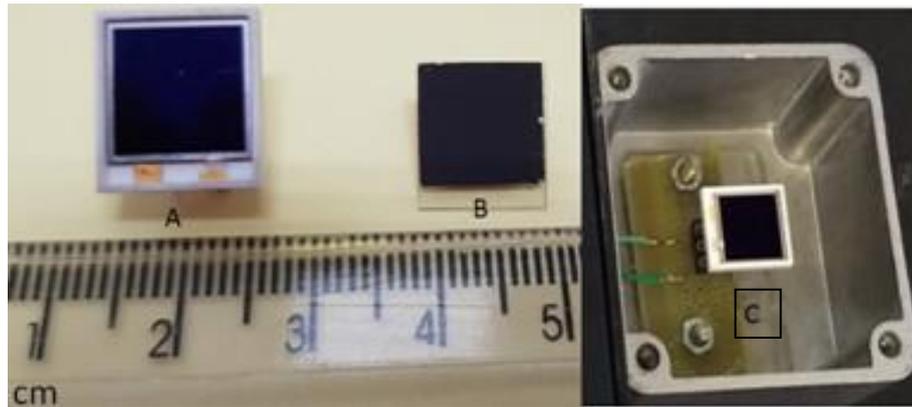


Figure 2: A. Boron layer(10 mm × 10 mm) over a microscope slide; B. Unsealed commercial photodiode with a (10 mm× 10 mm) active area. C. Photodiode inside the aluminum box.

Two prototypes were made, called prototypes 1 and 2, using different associated electronics. Prototype 1, shown in Fig. 3, consists of the detector device (photodiode+boron layer) coupled to a charge-sensitive preamplifier, an amplifier system, a counter system frequently used in industrial applications, and the power supply, all of them accommodated into a box. Prototype 2 (Fig. 3, right side), also has a charge sensitive preamplifier, now a different circuit construction, and an amplifier accommodated in a box, but in this case the power supply and the counter system, frequently used for digital pulses, are positioned into another box. In order to avoid electronic noise, the photodiode was positioned inside the aluminum box. The reverse voltage applied in both prototypes was 18 V.



Figure 3: Overview vision of the thermal neutron detector prototypes 1 (left) and 2 (right).

The electronic circuits of prototypes 1 and 2 are shown respectively in Figs. 4 and 5. The circuit of prototype 2 (Fig. 5) has advantages over that of prototype 1 (Fig. 4), such as, for example, the amplifier circuit that consists basically of an operational amplifier CI1 (model CS512 from Soshin) which is composed by a hybrid CI dedicated to photodiode uses, unlike the circuit of prototype 1 where the preamplifier is constituted by discrete transistors (non-integrated) – the amplifier circuit is equivalent in both prototypes, based on FET- type input integrated circuit (model TL084, model CA3140) – and on the discrimination circuit that allows the selection of the lower energy level of the radiation measured. The amplified pulse enters transistor Q1 (2N2222) which changes the impedance to couple to 50 Ω circuits. This output signal allows to measure the direct total counts or to evaluate the number of the counts using an energy spectrum generated by a multichannel analyzer (MCA).

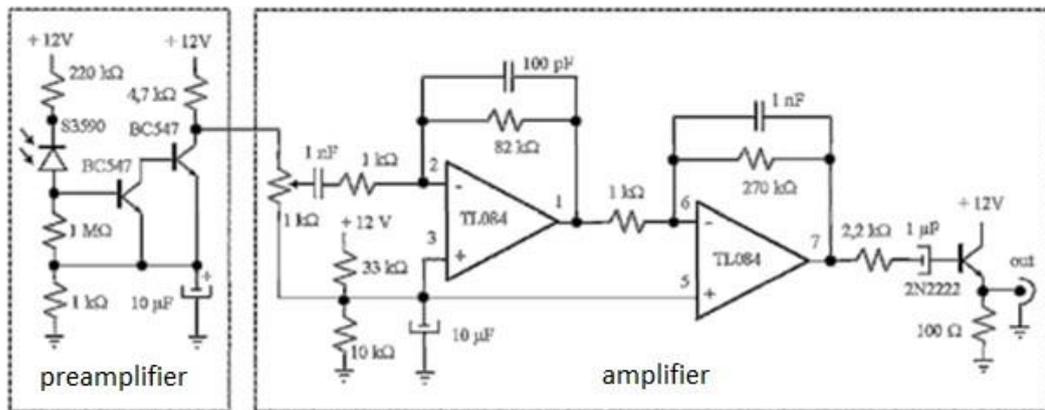


Figure 4: Electronic circuit of prototype 1 [4].

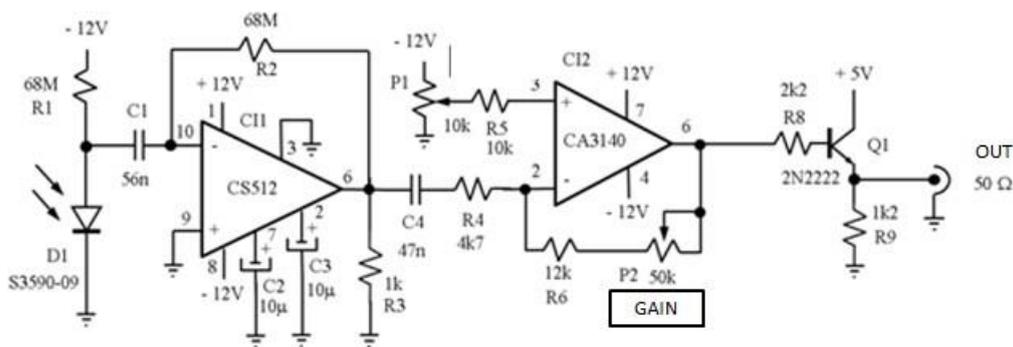


Figure 5: Electronic circuit of prototype 2.

2.2. Characterization of the prototype

The general setup used for characterization of the neutron detection systems is shown in Fig. 6, where it should be emphasized that the detectors' internal counters were not used in these measurements.



Figure 6: Concept of the setup for characterization of the neutron detection systems.

The prototypes proposed in this work uses a specific neutron converter that is recommended for measurements of thermal neutrons, it is important to note that as the value of cross section of ^{10}B for cold neutron for the energy of 4.86662 (6) meV is 8640 barns, and this value is 2.25 higher than the cross section for thermal neutrons. Which means that this prototype can be tested and use in both type of neutrons.

The characterization was performed using the cold neutron beam [5] at NCNR, that has a monoenergetic beam with 4.86662 (6) meV, which was collimated by borated aluminum masks. A borate glass attenuator (neutron transmission = 0.15) was positioned in front of this collimator in order to reduce the neutron flux producing a negligible dead time in the system. The flux value that arrives to the photodiode active region was $(1.07 \pm 0.09) \times 10^4 \cdot \text{s}^{-1}$. The neutron flux interaction in the characterization of the neutron detection system is illustrated in (Fig. 7), where the blue region indicates the boron layer and the brown one the photodiode. In this setup (Fig. 7) the linearity experiment was performed by varying the irradiation time at 0° position (surface area perpendicular to neutron flux direction), for both prototypes. Specifically for prototype 1, an angular dependence experiment was performed by varying the angle from -90° to 90° , in steps of 5° , with acquisition time of 10 min for each one.

The intrinsic efficiency [6] values for both prototypes were obtained using Eq. 1, where N is the number of neutrons that reach the active area of the detector every minute, $(6.4 \pm 0.5) \times 10^5$, and n is the number of counts registered in the same period.

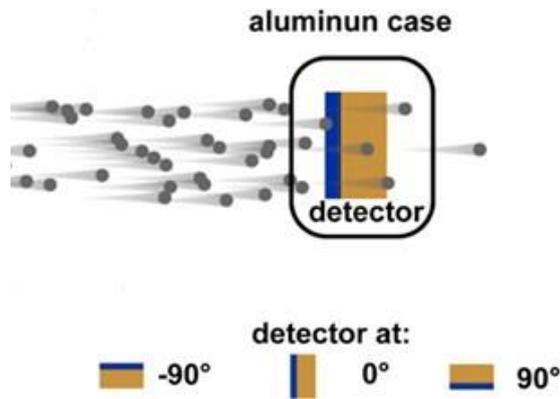


Figure 7: Concept of the neutron flux interaction with the aluminum case used in the characterization of neutron detection system.

$$\epsilon_{int} = \frac{n}{N} \quad (1)$$

3. RESULTS AND DISCUSSION

The results of the linearity experiment for prototypes 1 and 2 are shown in figure 8, showing that both presented a linear behavior. The angular coefficient from the linear fit of these graphics, given in count per minute (CPM), corresponds to the event rate r registered by the detector system; in prototype 1, $r = (8810 \pm 10)$ CPM and in prototype 2, $r = (33408 \pm 42)$ CPM. Consequently, the intrinsic efficiency of prototypes 1 and 2 are, respectively, $(1.37 \pm 0.01)\%$ and $(5.2 \pm 0.4)\%$.

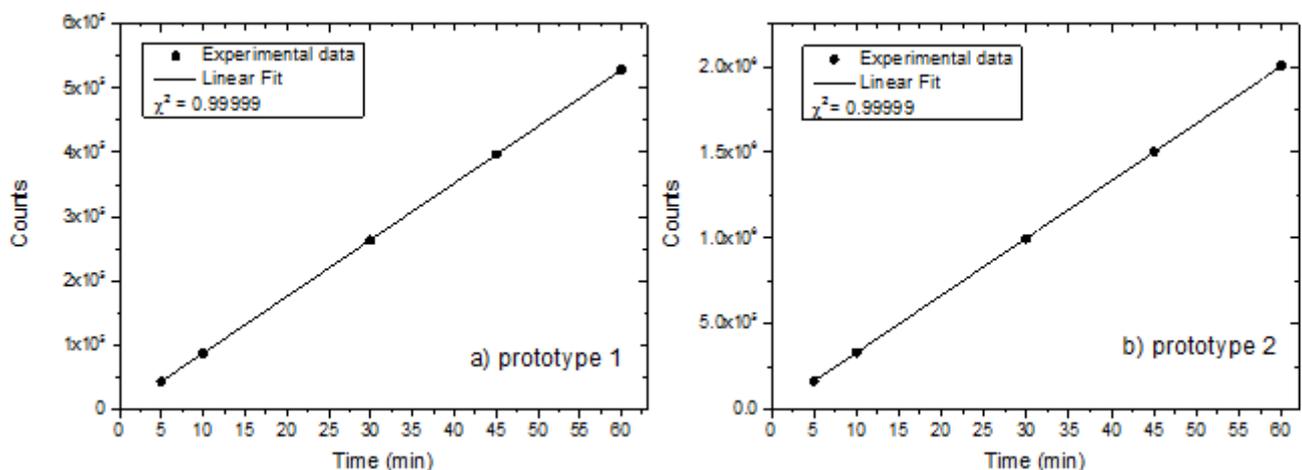


Figure 8: Counts as a function of time for neutron prototypes 1 (a) and 2 (b). Error bars are presented, but smaller than plot symbol.

The angular dependence of prototype 1 is shown in figure 9. The result shows that the highest efficiency is found at approximately 15° . The maximum of counts was expected at 0° although during the alignment between the boron layer and neutron source process this angle was dislocated 15° . The decrease in counts at 0° (7.7×10^5) in relation to 15° (1.0×10^6) is about 30%. Applying this 30% correction to the intrinsic efficiency, the new value is then $(1.78 \pm 0.01)\%$.

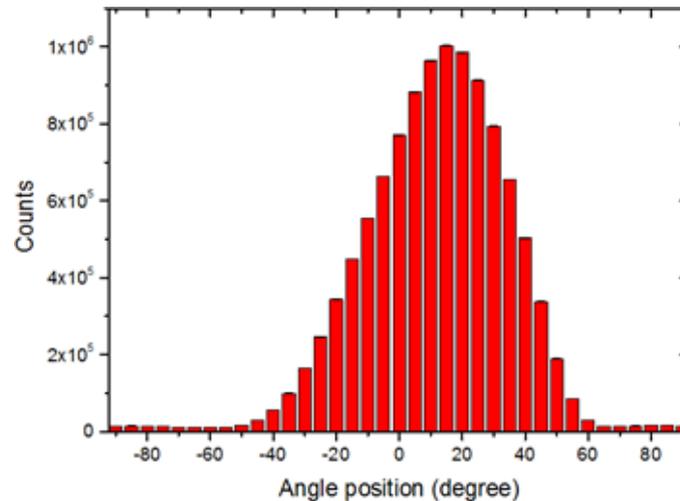


Figure 9: Counts versus incidence angle for neutron prototype 1.

4. CONCLUSIONS

The two thermal neutron detector prototypes were characterized and the intrinsic efficiencies obtained using a cold neutron beam were $(1.78 \pm 0.01)\%$ and $(5.2 \pm 0.4)\%$, respectively, for prototype 1 and 2. The difference between these systems lies on the preamplifier and counter system. As in the characterization the counters were not used, it is possible to infer that the preamplifier of prototype 2 presents a higher efficiency than that of prototype 1. Additional measurements should be carried in order to characterization the prototypes response to thermal neutron.

ACKNOWLEDGMENTS

We would like to thank the National Council for Scientific and Technological Development (CNPq) for the project (870240/1997-8).

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