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Evaluation of a PIN Photodiode Detector in Neutron-Gamma Fields

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Abstract. Semiconductor detectors are suitable for applications in radiation dosimetry in nuclear research reactors and for radiation protection purposes. The performance of these detectors depends on the quality of their semiconductor. The aim of this work was to evaluate a commercial PIN Photodiode in the neutron-gamma fields of the IEA-R1 nuclear research reactor and from an AmBe neutron source. This semiconductor was studied as a neutron detector using some types of converters to determine a dose-to-counts conversion factor to dose equivalent. The results have shown that this component may be implemented for assessing the neutron spectra in some radiation fields and in dose equivalent in radiation protection routines.

Keywords: experimental methods, nuclear instrumentation, semiconductor detector, neutron sources.
PACS: 29.25.Dz

INTRODUCTION

Semiconductor detectors are suitable for applications in radiation dosimetry due to their high density and lower energy required for the creation of electron–hole pairs in comparison to a gas detector, with 4–5 orders of magnitude less volume. Semiconductor detectors can be applied in personal, radiation accidents and radiation therapy dosimetry [1].

The main purpose of this research was the dosimetric evaluation of the semiconductor components for applications in dose equivalent estimates on dose fields from fast, epithermal and thermal fluxes using an AmBe neutron source and the IEA-R1 reactor neutrongraphy facility. Monte Carlo simulation metodology (MCNP) was employed to evaluate the paraffin thickness and the thermal flux in the case of the AmBe source [2]

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EXPERIMENTAL PROCEDURES

Detectors: PIN silicon photodiodes Hamamatsu S3590–04 were used as radiation detector in the experiments [3].

Moderator: For the AmBe neutron source case, a thick paraffin block was used as moderator. The neutron flux that results after thermalization is given in TABLE 1.

TABLE 1. Neutron flux after thermalization emerging from an AmBe source.

Neutrons	Energy (MeV)	Flux ($n.cm^{-2}.s^{-1}$)
Thermal	$E < 6.25\ 10^{-7}$	$4.22\ 10^{2}$
Epithermal	$6.25\ 10^{-7} < E < 1.0$	$9.94\ 10^{2}$
Fast	$1.0 < E < 15.0$	$1.38\ 10^{3}$
Total		$2.796\ 10^{3}$

Converters: In this work a ^{10}B converter which covers the radiation sensitive face of the semiconductor was used for thermal neutron detection [3, 4].

For fast neutron detection, a polyethylene converter as recoil proton generator was used. In order to fit the thicknesses X (cm) and counting rate R (cps), a mathematical model was implemented from a previous work [5].

Neutron sources: Measurements using a 37 GBq AmBe neutrons source from Amersham with an emission rate of $2.9\ 10^{5}$ $n.s^{-1}$ and the IEA-R1 reactor Neutrongraphy facility were carried out. Neutron fluxes and gamma-neutron dose equivalent were estimated previously [6, 7].

Channel calibration of data acquisition system was carried out through a low emission ^{241}Am and a 5.5 kBq mixed sources, both from AMERSHAM.

In order to develop the experiments, standard NIM electronics and the multichannel analyzer Maestro software from ORTEC were used for data acquisition and processing.

Thermal and epithermal neutron detection of an AmBe source and a neutron beam of the Neutrongraphy facility: the semiconductors S3590-04(A) and (B) were exposed to these neutron fluxes with the same converter and the results are given in Figures 1 and 2.

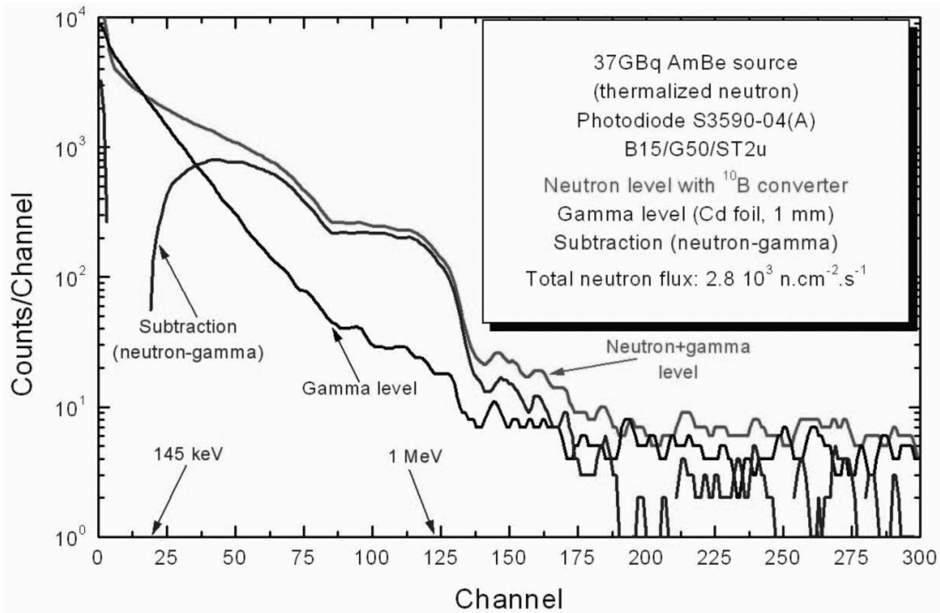

FIGURE 1 . Responses of photodiode S3590-04(A), covered with boron converter for thermal neutrons fluxes from AmBe source.

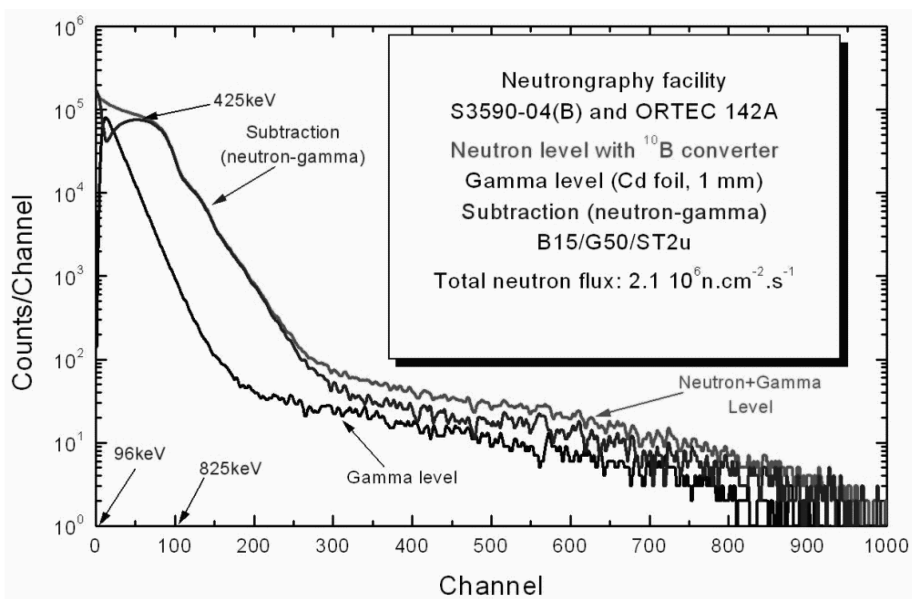

FIGURE 2 . Responses of photodiode S3590-04(B), covered with boron converter for thermal neutrons fluxes from the Neutrongraphy facility.

Fast neutron detection: the semiconductors, covered with a polyethylene foil, were exposed to these fast neutron fluxes without thermalization and the results were published in a previous work [8].

RESULTS

Dose to Counts conversion factor for thermal and fast neutron: Neutron sources generate gamma radiation, which can interfere in their neutron flux measurement. In this work we use a differential technique to discriminate this gamma radiation level, using 1 mm thick cadmium foil covering the sensitive detection area of the S3590-04 photodiode.

The role of the cadmium foil was to block the thermal neutron radiation, detecting only the gamma radiation as is shown in Figures 1a and 1b. The dose-to-counts conversion factor (*F*) is calculated using the equation 1 with *Dose* expressed in $mSv.h^{-1}$ and C_{cnt} in $counts.h^{-1}$ [9].

$$F = \frac{Dose}{C_{cnt}} (\mu Sv.counts^{-1}) \qquad (1)$$

The main purpose of this study was to relate the dosimeter detection counts to the corresponding dose and to find a dose-to-counts conversion factor. The results are shown in TABLE 2 and 3.

TABLE 2. Data and results for the dose-to-counts conversion factor

Photodiode S3590-04	**AmBe source Boron converter**	**AmBe source Polyethylene**	**Neutrongraphy Polyethylene**
Dose equivalent rate ($mSv.h^{-1}$)	4.96	850	25.7
Counts per hour ($C_{cnt}.h^{-1}$)	8950	39808	1526016
Conversion factor ($\mu Sv.(C_{cnt})^{-1}$)	0.5542	0.022	0.017

TABLE 3. Standard deviation and efficiency of the S3590-04 detector for thermal and fast neutrons using the data supplied by the software Maestro

Semiconductor	Counts.s^{-1}	SD	Efficiency (Th)	Efficiency (F)
S3590-04(A) (AmBe) (^{10}B)	2.48	1.58	0.25 %	-----
S3590-04(A) (AmBe) (P_y)	10.9	3.3	-----	0.1 %
S3590-04(B) (Neutr - ^{10}B)	19010	138	3.88 %	-----
S3590-04(B) (Neutrongr – P_y)	423.88	20.6	-----	0.086 %

Where *SD* is the standard deviation, P_y refers to polyethylene converter and ^{10}B means boron converter, *Th* and *F* is for thermal and fast neutron respectively. S3590-04(*A*) and (*B*) components means two same type semiconductors.

CONCLUSIONS

Using this type of PIN Photodiode, a spectrometer system may be implemented for assessing the neutron spectra in some radiation fields to be used such as: In radiation biological cultures BNCT (Boron Neutron Capture Therapy application), shielding calculation for radiation protection and for academic purposes.

Dose-to-counts conversion factor was established for dose equivalent in the thermal and epithermal neutron radiation fields of an AmBe neutrons source and the IEA-R1 reactor Neutrongraphy facility. By means of the Multichannel Analyzer Maestro software the detector efficiency was estimated. The dose estimation is valid only to these specific neutron sources. For other neutron spectrum, a new calibration and other considerations are needed.

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