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ELETRONIC RESPONSE OF A PHOTODIODE COUPLED TO A BORON THIN FILM

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ABSTRACT

A portable thermal neutron detector is proposed in this work using a silicon photodiode coupled to a boron thin film. The aim of this work was to verify the effect in the electronic response of this specific photodiode due to boron deposition, since the direct deposition of boron in the semiconductor surface could affect its electrical properties specifically the p-type layer that affects directly the depletion region of the semiconductor reducing the neutron detector efficiency count. Three boron depositions with different thickness were performed in the photodiode (S3590-09) surface by pulsed laser deposition and the photodiode was characterized, before and after the deposition process, using a radioactive americium source. Energy spectra were used to verify the electronic response of the photodiode, due to the fact that it is possible to relate it to the photopeak pulse height and resolution. Spectra from the photodiode without and with boron film deposition were compared and a standard photodiode (S3590-04) that had the electronic signal conserved was used as reference to the pulse height for electronics adjustments. The photopeak energy resolution for the photodiode without boron layer was 10.26%. For the photodiode with boron deposition at different thicknesses, the resolution was: 7.64 % (0.14 μm), 7.30 % (0.44 μm) and 6.80 % (0.63 μm). From these results it is possible to evaluate that there was not any degradation in the silicon photodiode.

1. INTRODUCTION

The availability of compact, portable and reliable detectors would be of interest for some neutron applications, such as the detection of nuclear weapons, drug inspections at customs and airports, worker protection in nuclear installations, or boron neutron capture therapy [1].

New devices for neutron detection [2-3] using ^{10}B and ^{6}Li as converters are already being developed as, although ^{3}He converter is more efficient, the access to this material is very limited and expensive [4]. In this work ^{10}B was chosen to be used as converter, due to the following characteristics: low cost, good microscopic cross section for thermal neutrons (σ_c=3840 b), it is not toxic [5] and is available commercially.

Neutron detector using photodiodes with boron can be obtained commercially [2] using ^{10}B or compound boron. For this purpose PIN photodiodes [3] and silicon wafer [4] are being used. Silicon photodiodes [1] are commercially available, have low cost, small size, their accompanying electronics are compact and work at room temperature. All this make silicon photodiodes good choices for this portable and compact thermal neutron detector has been under development.

The Boron layer in semiconductors could be coupled directly or indirectly to the surface of the device. Several techniques are used for fabrication of boron films, such as: magnetron sputtering [4], e-beam technique [6-7], Chemical Vapor Deposition (CVD) [3,8] and Pulsed Laser Deposition (PLD). In PLD, the use of excimer [9], Nd:YAG [10-13] and femtosecond lasers [14-15] have been reported.

However, layers of boron are not readily acquired [2] due to the high cost and difficult preparation. Also, as the evaporation temperature is high, it is difficult to fabricate boron films using traditional methods [12].

Boron films made using CVD technique have the disadvantage of using hazardous materials and need high temperature [13], magnetron sputtering [13] presents an amorphous surface, and in e-beam technique the film is not stable, has cracks and doesn't have good adhesion [12]. CVD has yet other disadvantages when compared to PLD [6]: contamination, residual stress and poor film adhesion.

Directly boron deposition by hot wire chemical deposition (HWCVD) has been performed over a silicon PIN detector [3] with active area of 10 x 10 mm^2, in the p-type layer with 0.4 μm of boron. That study showed that the direct deposition did not cause any degradation of the PIN detector [3].

For this work a commercially available Si PIN photodiode from Hamamatsu was used, in which a boron deposition layer was directly coupled by PLD. This device has the p-type layer formed by selective diffusion of boron to a thickness of approximately 1 µm [16]. In direct boron deposition by PLD the process of interaction of boron with p-type junction could occur mainly by two processes:

- ✓ Direct interaction with the p-type junction: in this case it will increase the amount of boron in this layer, and that could reduce the depletion layer resulting in a decrease of the detection efficiency of this semiconductor;
- ✓ Indirect interaction with the p-type junction: in this case a thin film layer is formed above the boron-doped area of the photodiode without affecting the junction properties.

The aim of this work is to verify the effect in the electronic response of a Si photodiode due to direct boron deposition by PLD technique. In order to achieve this goal a characterization of the photodiode after and before the deposition process was made using an americium source.

2. METHODS AND MATERIALS

The experimental setup used for obtaining the spectra of the photodiode (Fig 1) consists of a preamplifier and accompanying electronics. The photodiode was positioned inside the preamplifier encapsulation together with an americium source (^{241}Am). The voltage was applied in this system by an ORTEC 459 Bias Supply and a KEITHLEY 619 Electrometer/Multimeterammeter was connected in series in the circuit for measurement of the dark current. The electronic signal produced by the energy deposition of alpha particles was properly amplified (ORTEC 450) and processed by a multichannel analyzer (Software Maestro), resulting in experimental spectra.

Figure 1: Experimental setup.

As the purpose of this work is to verify the effect in the electronic response of a Si photodiode due to direct boron deposition, a commercially available PIN-type silicon photodiode model S3590-09, fabricated by HAMAMATSU with 10 x10 mm^2 active surface area, that had passed by a process of radioactive decontamination, was used.

Natural boron was directly deposited in the surface of this photodiode's active area by ultrashort pulse laser ablation. 25 femtosecond pulses generated by a Ti:Sapphire CPA amplifier (Femtopower Compact PRO HR/HP, Femtolasers) were focused on the surface of a rotating boron disk (Ø25mm × 3mm thickness) inside a vacuum chamber (10^{-5} mbar pressure). The disk rotation was used to avoid the formation of a cavity that would change the ablation geometry and stop the evaporation. The Si detector was placed at 35 mm from the boron disk. Three deposition processes were performed with different duration times, resulting in film thicknesses of (0.14 ± 0.02) µm, (0.44 ± 0.07) µm and (0.63 ± 0.08) µm.

The electronic signal of the photodiode was characterized before and after the deposition process using an americium source. From the obtained spectra, the photopeak resolutions were obtained using eq. 1. [17], in which FWHM is the full width at half maximum and H_0 is the peak centroid.

$$R(\%) = \frac{FWHM}{H_0} \times 100 \qquad (1)$$

Initially, a standard spectrum was obtained (black line, at Fig 2) with the Si photodiode S3590-04 whose pulse height was used as reference for the boron-deposited S3590-09 (blue line, at Fig 2). As the S3590-09 had its electronic signal modified due to the decontamination process, to ensure the same experimental electronic parameters, all experiments used the S3590-04 photopeak as standard.

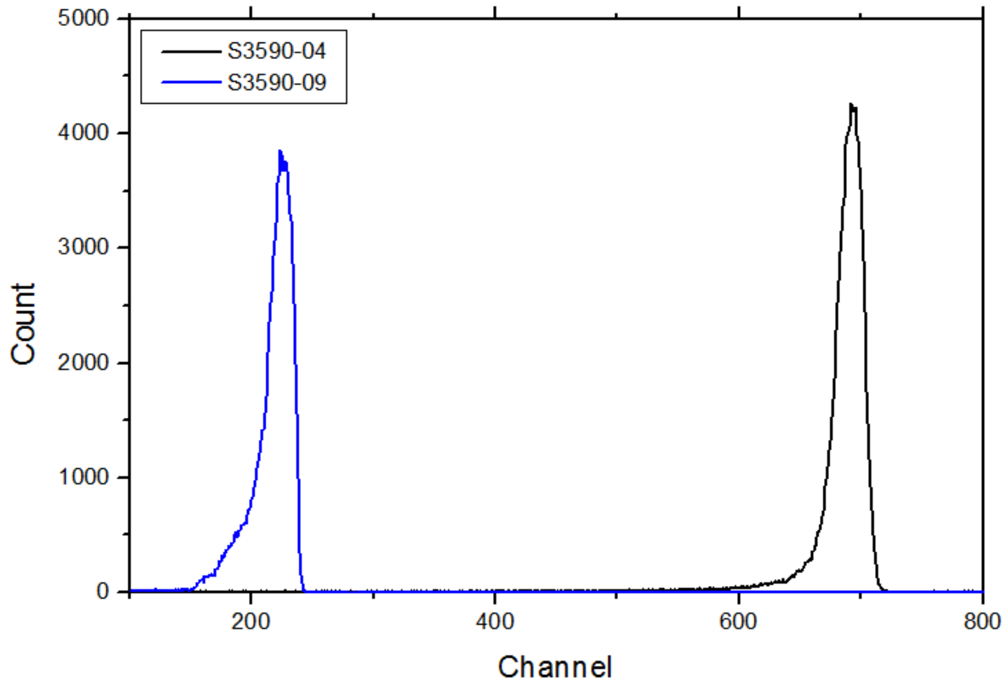

Figure 2: Spectra of photodiodes S3590-09 and S3590-04, with americium-241 source.

During all the experiments a reverse voltage of 50 V was applied to the photodiode. The experimental spectra were acquired in 300 s, with shaping time of 1µs and gain of 20x. The dark current and temperature were measured during the experiment. To improve the spectra, an aluminum collimator was used (Fig 3.a) between the photodiode and the americium source (Fig 3.b).

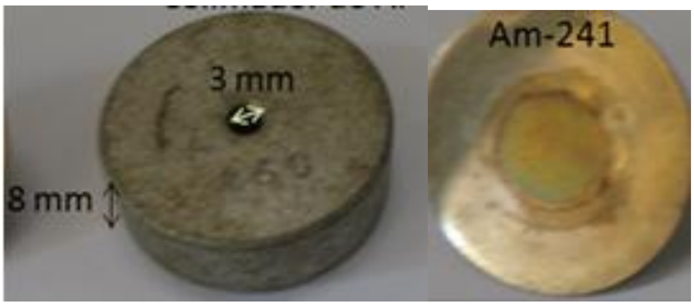

Figure 3: Aluminum collimator dimensions (a) and americium source (b).

3. RESULTS AND DISCUSSION

The comparison between the counts obtained from photodiode S3590-09 before and after boron depositions is shown in Fig 4.

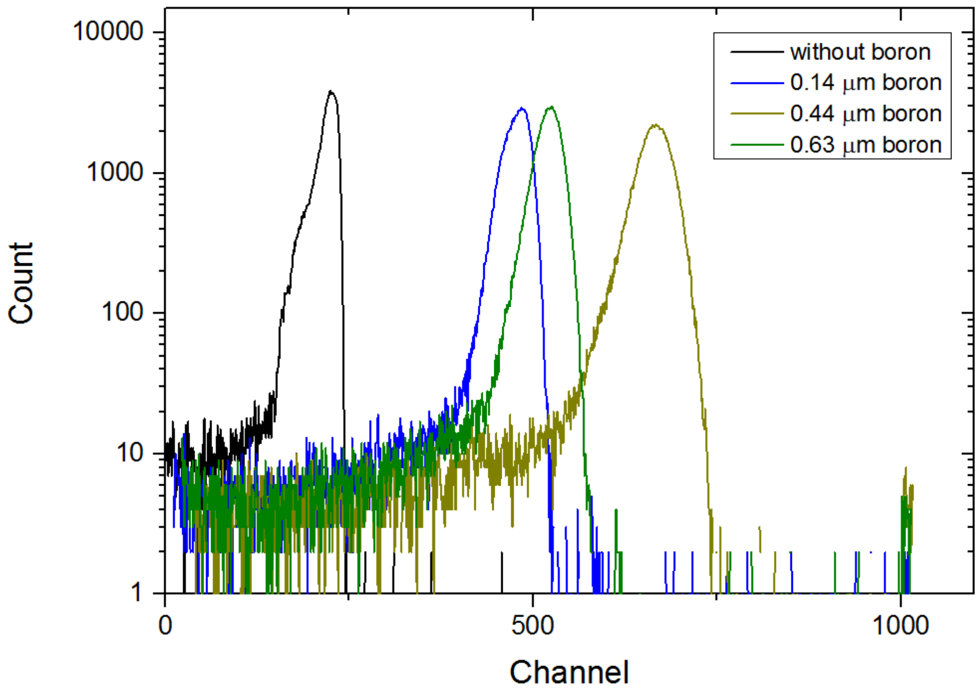

Figure 4: Spectra obtained with photodiode S3590-09 with and without boron film depositions.

The peak obtained with this photodiode changed position after boron was deposited (Fig 4), indicating an increase in the collection of electron-hole pairs. For boron thicknesses 0.14 and 0.44 μm, the peak moved right, and for 0.63 μm it moved left. This fact can be explained considering that boron deposition may have caused direct interaction with the p-type layer, increasing the amount of boron; that initially regenerated this layer, but after the third deposition the quantities of boron started to affect the depletion region of this semiconductor, affecting the charge collection. All the thickness values were estimated by measurements in an optical profilometer.

Energy resolution of the photodiode was obtained using the data from Fig 4 and equation 1, as shown in Table 1. The resolution improves drastically with the first boron deposition and was conserved after the other depositions, showing that the additional layer of the material doesn't affect the peak resolution.

Table 1: Relation of peak resolution in function of the thickness of the boron film

Film thickness (μm)	Resolution (%)
Without	10.26
0.14 ± 0.02	7.64
0.44 ± 0.07	7.33
0.63 ± 0.08	6.80

4. CONCLUSIONS

It was verified that the direct deposition of boron over the silicon surface using femtosecond PLD technique didn't cause noticeable damage in the electronic signal from the photodiode - instead, it improved the signal as the pulse height increased, indicating a better collection of electron-hole pairs, and enhanced the energy resolution of this photodiode. The fact that the mean pulse height from the photodiode with 0.63 μm of boron was lower shows that this increase may affect the depletion region. New studies will be made to verify this behavior.

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