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Measurement of the insensitive surface layer thickness of a PIN photodiode based on alpha-particle spectrometry

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1. Introduction

PIN photodiodes have been extensively used to detect charged particles and photons, either for dosimetry or radiation spectrometry [1-5]. Both applications require the precise measurement of the deposited energy in the sensitive volume of the diode by the incoming radiation. Due to the special structure of a PIN photodiode, where an intrinsic silicon layer is sandwiched between thin p and n-type layers, the sensitive volume is determined by whether an external voltage is applied or not. When used as a dosimeter, the diode is usually unbiased; thus, its sensitive volume depends on the relationship between its thickness and the minority carrier diffusion length. In contrast, the diode is reversely biased and fully depleted as a spectrometer to achieve the best energy resolution. However, regardless of being externally biased, the charged particles or weakly penetrating photons might lose some energy in an insensitive or dead layer before reaching the sensitive volume of the diode. This dead layer, which in the PIN structure consists of the SiO_2 layer developed on the device surface and the signal electrode (p-layer) thickness, always depends on the applied voltage being minimum at the full depletion condition. In this work, the insensitive layer thickness of a PIN photodiode (SFH206K - Osram) has been measured by varying the incident angle of a collimated monoenergetic alpha particle beam. This technique is based on the fact that, except for the intrinsic uncertainties of the emission and straggling of alpha particles, their trajectories at different incident angles are distinct, with smaller ones corresponding to the incidence perpendicular to the detector surface. Consequently, variations in the energy loss due to variable angles of incidence potentially worsen the energy resolution, mainly in charged particle spectrometry. Thus, measuring the dead layer thickness is essential to evaluate the energy loss and its influence on the energy resolution of the incoming radiation in several silicon devices often used in dosimetry and spectrometry systems.

2. Methodology

A PIN photodiode SFH206K, supplied by Osram, with an active area of 7.35 mm^2, a capacity of 72 pF (0 V), and dark currents smaller than 5 nA (0 V) is used in this work. To use this diode as a detector, the n^+ back pad was grounded while the reverse voltage was applied to the front pad (p^+). The signal from the detector was readout from the p+ electrode through a DC-coupled field-effect transistor (FET) in the first stage of a tailor-made charge-sensitive pre-amplifier based on the hybrid circuit A 250 (Amptek). The pulses from the pre-amplifier were shaped and amplified by a linear amplifier (ORTEC 572) with an adjustable shaping time constant and fed to a multichannel analyzer (ORTEC Spectrum Ace).
The diode and the pre-amplifier assembly were housed in a stainless steel chamber under 133 μPa pressure. The spectrometric characterization of the system was performed using a ^{241} Am source (5.486 MeV alpha particles), set up 2.0 cm away from the diode. The experimental parameters, such as reverse

bias voltage (24 V), amplifier gain (10), shaping time constant (2µs), and ADC channels (2048), were optimized to achieve the best statistic counting and energy resolution.
Measurements of the insensitive layer of the photodiode were performed with alpha particles hitting the front surface of the diode at incidence angles (θ) ranging from 90° (normal incidence) down to 30° in intervals of 10°. At all angles of incidence, related to the surface of the diode, the corresponding energy spectra were recorded to attain the respective energy resolutions and the peak's centroids, which are essential to calculate the thickness of the dead layer. It is based on the energy loss of alpha particles with different path lengths in the diode due to distinct incident angles, as can be seen in Fig. 1.

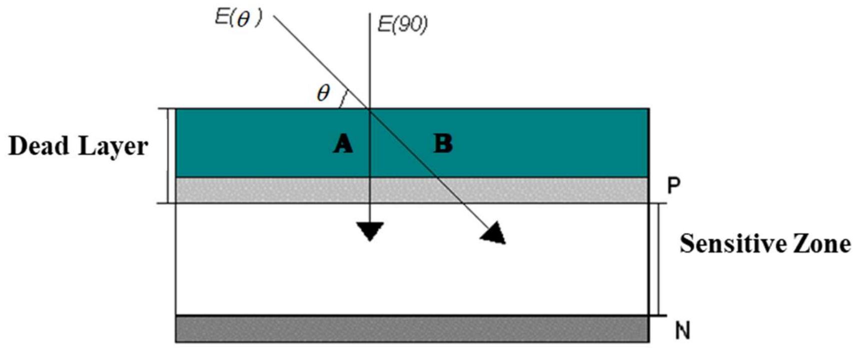

Figure1: Energy loss in the dead layer of alpha particles hitting the surface of the diode at different angles.

From Fig. 1, the energy of alpha particles after their energy loss in the dead layer is given by Equation 1, for a normal incidence (90°), and Equation 2, for an incidence angle θ:

$$E(90) = E_0 - \frac{dE}{dx} \cdot A \tag{1}$$

$$E(\theta) = E_0 - \frac{dE}{dx} \cdot B \Rightarrow E(\theta) = E_0 - \frac{dE}{dx} \cdot \frac{A}{sen\theta} \tag{2}$$

Where, E_0 is the initial energy of the incident alpha particle, *dE/dx* is the linear stopping in the silicon material, and *A* is the dead layer thickness. So, the difference between $E(90)$ and $E(\theta)$ is given by:

$$E(90) - E(\theta) = \Delta E = \frac{dE}{dx} \cdot A \cdot \left(\frac{1}{sen\theta} - 1\right) = \frac{dE}{dx} \cdot A \cdot Z \tag{3}$$

The geometric factor Z (inside the parentheses in equation 3) only depends on the incidence angle of alpha particles related to the surface of the diode. Experimentally, the product of dead layer thickness and the stopping power is assessed by the slope of the linear plot of the energy variation of the alpha particles as a function of the geometric factor.

3. Results and Discussion

Fig. 2 shows the best and the worst resolution energy spectra of ^{241}Am alpha particles that hit the front surface of the diode at incident angles of 90° and 30°, respectively. This figure reveals the significant incidence angle effect on both the energy resolution and the energy effectively deposited in the sensitive volume of the diode. In fact, at a 30° incident angle, the peak centroid shifts to a lower channel position revealing a greater loss of energy and a worse energy resolution compared to those values achieved at a 90° angle. These statements hold for the energy resolution results achieved at different incident angles exhibited in Fig. 3.

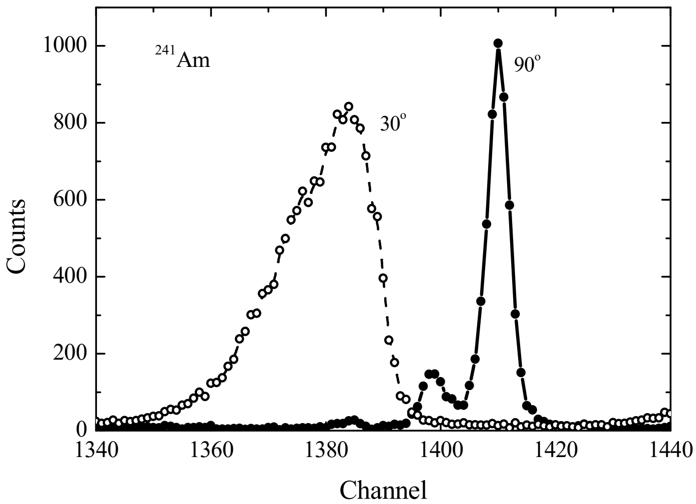

Figure 2: Energy spectra of alpha particles with incident angles of 90° and 30° related to the surface of the diode. V= 24 V.

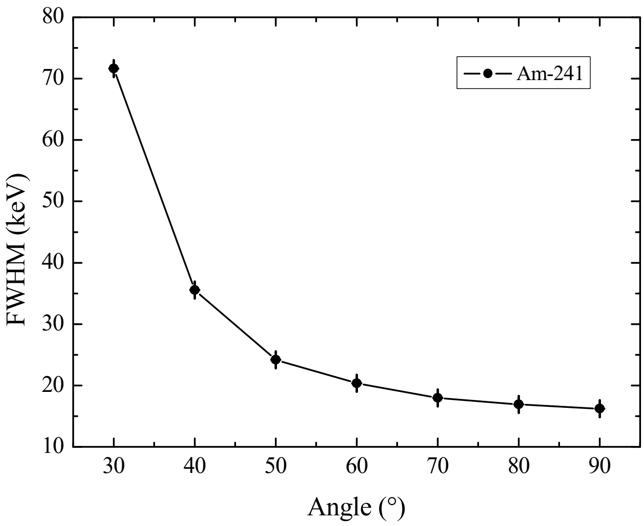

Figure 3: Variation in energy resolution of alpha particles with an incident angle range of 30° - 90° related to the surface of the diode.

Fig. 4 shows the plot of the peak's centroids shift, converted in energy variation from a calibration curve previously established for the spectrometry system, as a function of the geometric parameter Z. It is important to note the increase in the data uncertainty attained at the more oblique incidence of the alpha particles. It is due to the energy resolution degradation (Fig. 3) that compromises the data fitting and the corresponding centroid of the peaks.

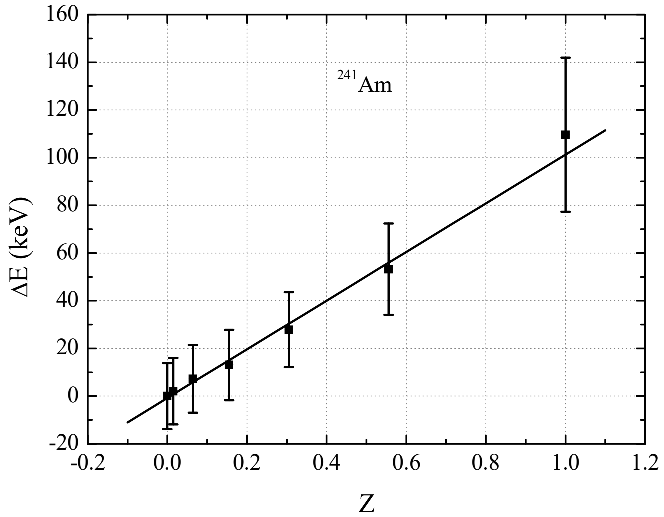

Figure 4. Energy variation as a function of the geometric parameter Z.

Based on the linear coefficient of the plot (102 keV), the alpha particle energy (5.486 MeV), and the linear stopping power in the silicon dioxide (143.6 keV/μm), the dead layer thickness of the diode is found to be (711 ± 23) nm.

4. Conclusions

In this work, the dead layer thickness of a PIN photodiode (SFH206K - Osram) is proposed to be measured by varying the incident angle of a collimated monoenergetic alpha particle beam upon its surface. The result obtained (711 ± 23) nm, less than 1% of the intrinsic layer thickness, besides validating the employed method, demonstrates that the diode herein investigated is suitable for high resolution charged particle spectrometry.

References

[1] P. H. Gooda, W. B. Gilboy, “High resolution alpha spectroscopy with low cost photodiodes”, *Nucl. Instrum. Methods Phys. Res.* vol. 255, pp. 222–224 (1987).

[2] C. C. Bueno, J. A. C. Goncalves, M. D. de S. Santos, “The performance of low-cost commercial photodiodes for charged particle and X-ray spectrometry”, *Nucl. Instrum. Methods Phys. Res.* vol. 371, pp. 460–464 (1996).

[3] H. J. Khoury, H. Schelin, D. Soboll, N. Lunelli, C. Baptista, “Evaluation of comercial silicon diode for electron dosimetry”, *Nucl. Instrum. Methods Phys. Res.* vol. 580, pp. 537–539 (2007).

[4] J. A. C. Goncalves, A. Mangiarotti, C. C. Bueno, “Current response stability of a commercial PIN photodiode for low dose radiation processing applications”, *Radiat. Phys. Chem.* vol. 167, pp. 108276 (2020).

[5] A. A. Malafronte, A. R. Petri, J. A. C. Gonçalves, S. F. Barros, C. C. Bueno, N. L. Maidana, A. Mangiarotti, M. N. Martins, A. A. Quivy, V. R. Vanin, “A low-cost small-size commercial PIN photodiode: I. electrical characterisation and low-energy photon spectrometry”, *Radiat. Phys. Chem.* vol. 179 pp. 109103-109113 (2021).