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ELECTRICAL CHARACTERISTICS AND ALPHA PARTICLE DETECTION PERFORMANCE OF A NEWLY DEVELOPED PIN PHOTODIODE

Ercan Yilmaz[1,2*], Emre Doganci[1,2], Farid Ahmadov[3,4], Gadir Ahmadov[4,5], Azar Sadigov[4,5], Samir Suleymanov[3]

[1]Physics Department, Bolu Abant Izzet Baysal University, Bolu, Turkey
[2]Nuclear Radiation Detectors Application and Research Center (NÜRDAM), Bolu Abant Izzet Baysal University, Bolu, Turkey
[3]The Center for Strategic Scientific Research of ANAS, Baku, Azerbaijan
[4]National Nuclear Research Centre of MCHT, Baku, Azerbaijan
[5]Joint Institute for Nuclear Research, Dubna, Russia

Abstract. *The Silicon PIN photodiodes (Si-PIN) with an active area of 5.0 x 5.0 mm² were designed and fabricated by using a conventional photolithography process at the Center of Nuclear Radiation Detectors Research and Application (NÜRDAM) for the investigation of electrical characteristics and alpha particle detection performance. To obtain the device electrical specifications, the current-voltage (I-V) and the capacitance-voltage (C-V) measurements were carried out in the photoconductive mode. The Si-PIN photodiode was then used to detect alpha particles from different radioactive sources in a vacuum at room temperature. Photodiode dark current and capacitance were measured and found to be – 20 nA and 23pF, respectively, at -20 Volts (the operating voltage used during alpha particle detection). The possibilities of improving the parameters of the photodiode are discussed.*

Keywords: *Si-PIN photodiodes, alpha particle detection, photodiodes*

1. INTRODUCTION

Silicon PIN photodiodes (Si-PIN) with their structural feature are more convenient devices to measure ionizing radiation than simple PN junction diodes [1]. In addition, Si-PIN diodes can be fabricated at low cost, with good energy resolution and in small size compared to scintillation detectors, and gas-filled detector [2]. Many studies were published about the performance of the Si- PIN photodiode detectors under ionized particles. Different types of Si-PIN photodiodes were utilized with various architectures as a radiation detector and particle counter [3-6]. In this study, newly designed Si-PIN photodiodes were fabricated and the initial capacitance and current characteristics investigated. Detection performance of this Si-PIN photodiode sample with a 5.0 x 5.0 mm² active area was evaluated under alpha particles of different energies.

2. EXPERIMENTAL METHOD

2.1. Si-PIN Photodiode Fabrication

A slightly doped 500µm (100) N-type Si substrate having approximately 2.4 kΩ.cm surface resistivity was cleaned by the Standard America Cleaning Application (RCA) process and was dried with ultra-pure nitrogen gas. Immediately after the cleaning process, Silicon 1µ layer dioxide was grown by wet oxidation at 1100 °C. The p+ and n⁻ regions were opened with standard photolithography and chemical etching process where the doping was carried out separately. Boron tribromide gas (BBr_3) and Phosphorus Oxychloride gas ($POCl_3$) were used at 950 °C in diffusion furnace to formate p⁺ an n⁻ region respectively. Metal contacts were formed by dc sputtering.

2.2. Electrical Measurements of Si-PIN Photodiode

The I-V characteristics of the Si-PIN photodiode were measured by KEITHLEY 2636B source meter, and C-V characteristics were measured by HIOKI 3532 LCR meter on photoconductive mode.

2.3. Experimental Setup for Alpha Particle Measurement

The diagram of the experimental setup is depicted in Fig.1. The Si-PIN photodiode and an amplifier were installed in a vacuum chamber at a distance of about 8 cm from the sources of the alpha particle. The *pressure* of the vacuum chamber was 2 mbar. The collimator was located between the source and the PIN diode; it was used to accurately detect the energy of the alpha particle that was absorbed only in the active area of the device. The size of the collimator was 4×4mm.

* yilmaz@ibu.edu.tr

The tested Si-PIN device had an active area of 5 × 5 mm^2.

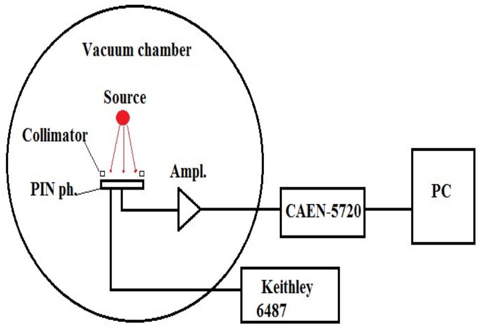

Figure 1. Experimental setup for alpha particle measurement

In our measurements, the signal from Si- PIN device was fed to preamplifiers with signal gain from 110 (BW~70MHs) and was recorded with a CAEN DT5720B digitizer module with 12-bit resolution and 250 MS/s sampling rate. The integration window was set to 100 ns. All measurements were carried out at room temperature. The radionuclide Ra-226 was used as the source of alpha particles. The energy of the emitted alpha particle ranged from 4.6MeV to 7.68MeV. The Ra-226 and daughter products principally emitted 4601 keV (Ra-226), 4784.34 keV (Ra-226), 5489.48 keV (Rn-222), 5304.33 keV (Po-210), 6002.35 keV (Po-218) and 7686.82 keV (Po-214) alpha particles with the corresponding yields per decay of 5.94%, 94.05%, 100%, 1%, 100% and 100%.

3. Result And Discussion

3.1. Results of I-V and C-V measurement

The I-V measurements of Si-PIN photodiodes are illustrated in Fig. 2. They were performed at room temperature in a dark environment. The dark current (I_{dc}) measurements are illustrated in Table 1. When the applied reverse voltage increased, the I_{dc} increased until the voltage reached the breakdown voltage. The measured I_{dc} values are in good agreement with the mathematical model [7] that explains the dependency of the diffusion current to the active area of the diodes and the current created in the depletion area. In addition, the dark currents of our measurements are possibly from the tunneling effect and the active states in the intrinsic (I) region as reported in [8]. As the applied reverse voltage is increased further to the breakdown voltage, the dark current reaches its upper limit. This indicates that each fabricated Si-PIN photodiode may exhibit its own specific high voltage. The breakdown voltage (V_{br}) is determined from the voltage value that corresponds to 10 μA current.

The typical C-V measurement of the Si-PIN photodiode is illustrated in Fig. 3. Small capacitance values are required for high sensitivity and high operational speed devices [9]. The capacitance value vs. reverse bias voltage dropped sharply between 0 V and – 5 V initially. As the reverse bias voltage increased further, the capacitance values decreased slightly as shown in Fig. 3. This shows that the photodiodes proceed to work in full depletion mode at – 5 V. The C and I_{dc} values of photodiodes are listed in Table 1 at the fully depleted voltage.

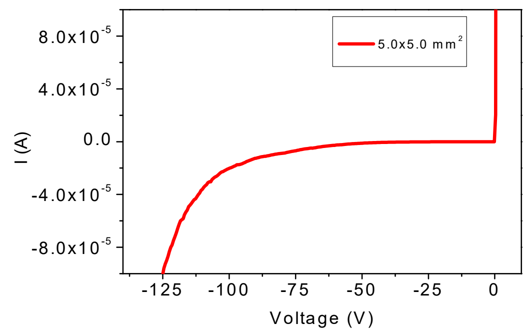

Figure 2. I-V measurement results

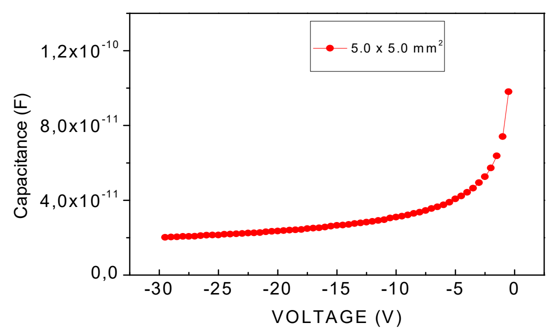

Figure 3. C-V measurement results

Table 1. I-V and C-V measurement results

Active Area mm^2	Dark Current (I_{dc}) @ -5V	Breakdown Voltage (V_{br})	Capacitance @ -5V
5.0x5.0	- 9 nA	- 84 V	40 pF

3.2. Results of Alpha particle Measurement

The Si-PIN diode detector response after exposure to alpha particles from the Ra-226 source is shown in Fig. 4. The measurement time is selected to be 1000 sec. Two peaks are observed from the pulse height distribution of the Ra-226 source. The first peak is related to the alpha particles with the energy range from 4.6MeV to 6 MeV and consists of five overlapping peaks. This overlapping is related to poor energy resolution of the detector. The second peak corresponds to the alpha particle at 7.68MeV. The Si-PIN diode has an energy resolution of 11% at 7.68MeV. The poor energy resolution is related to the loss of charge produced by the alpha particle in the Si-PIN diode.

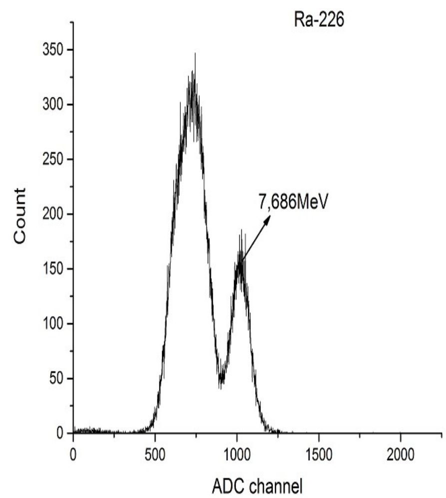

Figure 4. Pulse height distribution for the Ra-226 source detected with the Si-PIN diode.

4. Conclusion

The high dark current observed is related the absence of a stop channel (guard ring). The low energy resolution of the PIN diode for the alpha particle is related to the thickness of the top layers (SiO2 and p layer) which do not allow efficient collection of the charge produced by the alpha particle.

The obtained experimental results allow proposing the following steps to improve the parameters of the Si-PIN diode:

a) Using the stop channel to reduce the dark current;
b) The thickness of the p^+ layer should be reduced and it will be about 100nm;
c) The thickness of the SiO_2 layer should be reduced and it will be about 60nm.

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