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Effects of Alpha Radiation on Silicon Carbide Photodiode I-V Curve

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ABSTRACT

In this paper, we study the effects of alpha radiation on silicon carbide (SiC) photodiode IV curve. Recently, SiC photodiode is widely used as a radiation detector. In this work, we used Am-241, which mainly emits alpha radiation as the radiation source. The aim is to study the effects of Am-241 alpha radiation on the SiC photodiode current-voltage (I-V) characteristic curve. The obtained results after the Am-241 alpha irradiation has minimal impact on the I-V profile as compared to before the radiation. Nevertheless, the SiC photodiode forward current is reduced from 20.0 mA to 19.6 mA with biasing voltage is at 2 V.

1. Introduction

Radiation term has been used to describe electromagnetic waves in 1900. Around that time, electrons, X-rays, and natural radioactivity have also been discovered and included under the term radiation. Today, it refers to the whole electromagnetic spectrum as well as to all the atomic and subatomic particles that have been discovered [1]. In physics, radiation is referred to as the emission or the transmission of the energy in the form of waves or particles through space or the material medium [2]. Generally, radiation can be categorized into two types, which are ionizing and nonionizing radiation. Ionizing radiation includes X-rays, alpha, beta, and gamma, and it comes from the nuclei of atoms, the basic building blocks of matter. Nonionizing radiation is the radiation within the electromagnetic spectrum with sufficient energy to excite atoms or electrons, but insufficient energy to remove electrons from an atom or to cause ionization [3].

Radiation detection has long been of fundamental interest in a wide range of areas such as environmental awareness and the nuclear forensics of radioactive materials [4]. For example, the Fukushima nuclear accident motivated citizen scientists to collect and share radiation data across the world [5]. Detection of radiation starts with the interaction of the radiation with matter, resulting in a conversion of the energy of the radiation into the generation of photons (light), electrical charge, or heat. Some works have used the sensor networks to detect and track radiation [6]. Recently, radiation sensing is being widely applied to areas such as scientific analysis, safety systems, health

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care, and numerous others. This results in an increasing demand for low cost and reliable radiation sensing devices in the market [7].

SiC-based semiconductor radiation detectors and electronic circuits are presently developed for the uses in high-temperature and high radiation conditions where conventional semiconductor detectors cannot adequately perform.

The objectives of this work are to study the effects of Am-241 [8] alpha radiation on the SiC photodiode forward-biased IV characteristic curve and to measure the strength of the Am-241 alpha radiation. This study is necessary to verify the effect on the IV curve of the photodiode after alpha-particle irradiation.

2. Literature Review

2.1 SiC Photodiode

The SiC has excellent thermal stability, and it is expected to be one of the ceramic materials that can be used at high temperature [9]. The SiC is a better radiation detector as it has higher band gap energy and radiation resistance. The wide band gap energy and low intrinsic carrier concentration allow SiC to maintain semiconductor behavior at a much higher temperature than silicon, which in turn permits SiC semiconductor detectors to function at a much higher temperature than silicon detectors. Previous works on Yttrium Tantalum Oxide Doped with Terbium (Tb-YTaO4) and Soda Lime Silica (SLS) glass doped with Lanthanum oxide (La2O3) have shown that radiation detection is not functioning well at high temperature [10] and [11].

SiC radiation detectors are radiation resistant detectors, which means that the detector's parameters are not or very little affected by exposure to radiation. Materials like SiC lead to a detector capable of operating in high radiation fields [13]. Some preliminary work at USM with SiC synthesized via reaction of Silicon Tetrachloride (SiCl4) with Aluminum carbide (Al4C3) have shown it can be used as radiation detector [14]. Most of these detectors are radiant resistant at normal operating biasing voltage.

2.2 Americium-241 (Am-241)

AM-241 is the most common isotope of americium, and it is radioactive. It can be easily found in ionization type smoke detectors. It has a half-life of about 432.2 years [8]. AM-241 is an alpha emitter with a weak gamma-ray by-product. Alpha particles are energetic nuclei of helium with an average energy of 5486 keV. The production of alpha particles is usually termed as alpha decay. Thus, they are not very penetrating, and a piece of thin paper can stop their penetration. The alpha particles can only travel for a few centimeters as they end up deposit all their energies along this short path. Due to its low penetration of alpha radiation, it only poses a health risk when ingested or inhaled.

3. Methodology

3.1 Project Flow

Figure 1 depicts the flow of the overall methodology for this project. This work was carried out based on Figure 1 to achieve or fulfill all the objectives. At the beginning of the project, some theories and studies about the radiation sensor circuit were conducted.

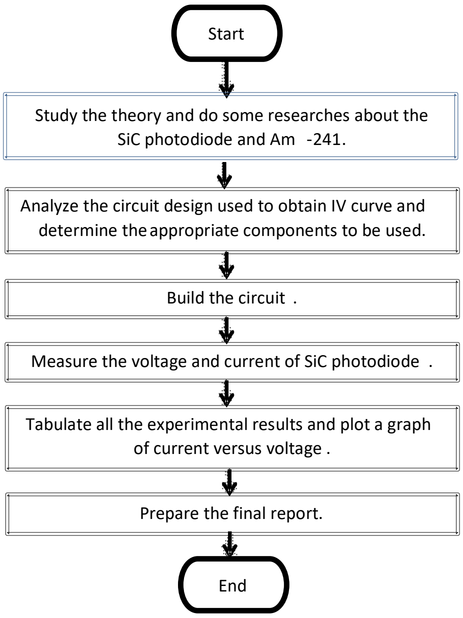

Fig. 1. Flow Chart of Overall Work

3.2 Reaction of SiC Photodiode

When the SiC photodiode is exposed to Am-241 alpha radiation, it will absorb primarily alpha particles. When the alpha particles are absorbed in the SiC photodiode, the current is induced. This is because when the SiC photodiode is struck by a particle of alpha rays, which has sufficient energy, an electron-hole pair is created. This mechanism could be similar to the inner photoelectric effect. In this region, the holes are moving toward the anode, and the electrons are moving toward the cathode. Thus, an alpha-particle current is induced. The total current that was passing through the SiC photodiode is equal to the sum of the induced and the dark current. Dark current is a current that is generated in the circuit in the absence of radiation or light. SiC photodiode has a low value of dark current, which is on the scale of femtoampere (fA). Therefore, the total current passing through the SiC photodiode is assumed to be the induced current only.

3.3 I-V Characteristic of SiC Photodiode

A circuit is used to obtain the I-V characteristic curve of the SiC photodiode before and after the alpha-particle radiation for 24 hours. The schematic design of the circuit is shown in Figure. 2.

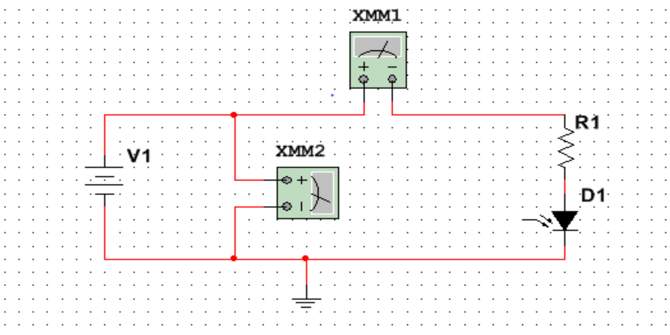

Fig. 2. Schematic Design of the Circuit to Obtain I-V Characteristic of SiC Photodiode

The SiC photodiode was kept together with the Am-241 for 24 hours. This was done to ensure considerable exposure period to the SiC photodiode. The I-V of the SiC photodiode was obtained by using a voltmeter and a milli-ammeter in a laboratory. In this work, the SiC photodiode was SIC01S-18 UV photodiode in a TO18 package.

3.4 Measurement of AM-241Alpha Radiation

A Geiger Muller counter (GQ Geiger Counter) was used to determine the radiation counts/intensity of Am-241. The Am-241 was placed directly near the Geiger Muller counter to improve the accuracy of the results. Radiation intensity follows the inverse distance law [1]. The radioactivity and the ionizing radiation dose of the Am-241 were displayed on the data logger that was installed on a computer.

4. Results

4.1 I-V Characteristic of SiC Photodiode

Table 1 shows the I-V of the SiC photodiode before and after the alpha radiation for 24 hours, while Figure 3 shows the I-V curve for the SiC photodiode before and after the irradiation.

Table 1
I-V of the SiC Photodiode Before and After Radiation for 24 Hours

Voltage (V)	Before Radiation Current, mA	After Radiation Current, mA
0	0	0
0.2	0	0
0.4	0.5	0.5
0.6	1.0	0.9
0.8	2.0	1.95
1.0	3.0	2.80
1.2	5.0	4.80
1.4	7.5	7.40
1.6	10.0	9.80
1.8	15.0	14.70
2.0	20.0	19.60

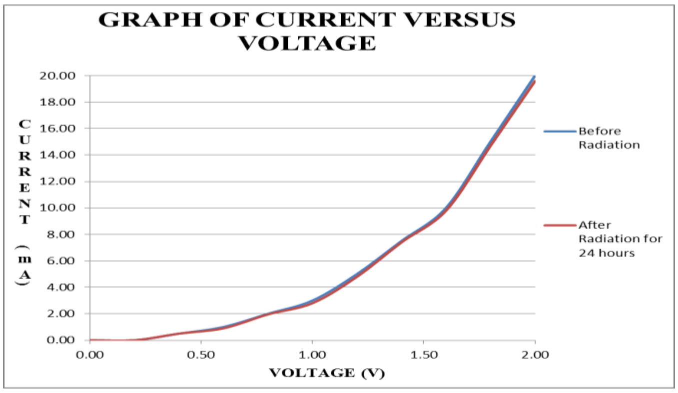

Fig. 3. I-V Curve of the SiC Photodiode Before and After Radiation for 24 Hours

Based on Table 1 and Figure 3, the results obtained after the Am-241 alpha irradiation do not have a significant difference in the I-V profile as compared to before the radiation at low biasing voltage. This means that Am-241 alpha radiation has a minimal effect on I-V for SiC photodiode at that biasing voltage. Only at higher biasing voltage, the effect on I-V looks significant.

4.2 The Strength of Am-241Alpha Radiation

Figure 4 shows the radioactivity and the ionizing radiation dose of the Am-241 in 60 seconds.

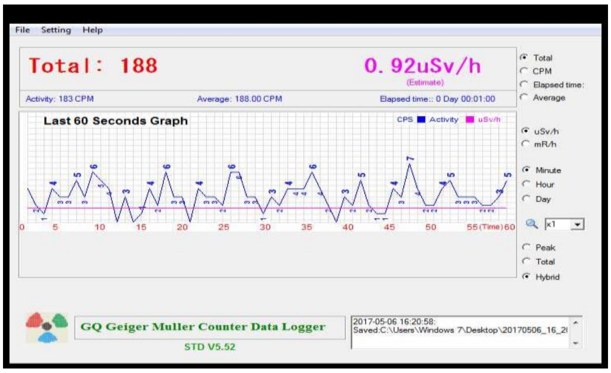

Fig. 4. Radioactivity and Ionizing Radiation Doze of Am-241 in 60 Seconds in micro-Sieverts per hour (µSv/h)

From Figure 4, the average ionizing radiation dose of Am-241 is estimated to be 0.92 µSv/h (9.2E-7 J/kg.h) in 60 seconds. This value of the ionizing radiation dose of Am-241 is low and not significant. The energy of Am-241 particles was approximately equal to 5486 keV.

5. Conclusions

The forward current of the SiC photodiode is slightly reduced after the irradiation of SiC photodiode by Am-241. The effect is noticed when the SiC photodiode is biased at a higher voltage. Therefore, the SiC photodiode is potentially still a suitable radiation sensor, which can be used to detect the particle radiation even after prolonged exposure to alpha radiation radiated by Am-241. Authors believe a further study is required to determine the root cause of the effect on the SiC photodiode IV curve.

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