بسم الله الرحمن الرحيم

Sudan University of Science& Technology

Faculty of Graduate Studies

The effects of Cs-137 gamma photons on the electrical characteristics of Silicon diode 1N4007

تاثير أشعة غاما من مصدر السيزيوم-137 علي الخصائص الكهربية لثنائي السيليكون1N4007

Thesis submitted in partial fulfillment for the requirements of M.Sc in Physics

By:

Afraa Khamies kajo Konda

Supervisor:

Dr. Nassreldeen Abdelrazig Abdelbari Elsheikh

November,2014

Sudan

بسم الله الرحمن الرحيم

قال تعالى :

(وما اوتيتم من العلم الا قليلا)

صدق الله العظيم

سورة الاسراء الايه (88)

DEDICATION

To my great father and my dear mother.

To those who give more than take.. my friends.

To all my teachers.

And to those whom I love.

ACKNOWLEDGEMENTS

Thanks for god for his guidance in all my academic years. My thanks and gratitude to my supervisor Dr. Nassreldeen Abdelrazig Abdelbari Elsheikh, and lots of thanks to Sudan University for Science and Technology, Faculty of science, department of physics, and special thanks for all members of the physics Laboratory.

ABSTRACT

In this thesis, experimental measurements were carried out to determine the radiation induced effect on the electrical properties of silicon based diode type 1N4007. The gamma ray photons of Cs-137 source were used to irradiate the diode under test. The results in terms of IV characteristics were compared for post and pre irradiated diode. It is found that the forward current has increased with respect to operating voltage (0.7V) by about 42%.

Furthermore, the possibility of using cement powder to shield the diode under test was explored. The results for bar and shielded diode were compared pre and post irradiation. It is found that the presence of cement coating has effectively shifted the current values to near normal regions with respect to operating voltage for silicon diodes.

مستخلص

في هذه الاطروحة قمنا بإستخدام ثنائي السيليكون (الدايود) لدراسة تاثير اشعة غاما من المصدر Cs-137 علي اشباه الموصلات، حيث قمنا بتشعيع ثنائي السيليكون 1N4007 لتحديد تاثير الاشعاع على الخصائص الكهربائية للثنائي، ثم قيست النتائج وقورنت بتلك التي اخذت قبل تشييع الثنائي موضوع البحث، ووجد ان هنالك زياده في التيار بنسبة 42% عند النقطه المقابله لجهد التشغيل (0.7 V).

كذلك في هذه الدراسة تم استخدام مسحوق الاسمنت كطبقة خارجية لتدريع الثنائي،، وبعد مقارنة الخواص الكهربائية للثنائي المشعع قبل وبعد التدريع ، وجد ان طبقة مسحوق الاسمنت عملت بكفاءة وقللت من التلف المستحث بواسطة اشعة غاما وذلك بارجاع الخصائص الكهربيه الطبيعيه للثنائي موضوع البحث.

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INTRODUCTION

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INTRODUCTION

1. 1 Introduction

All devices used by mankind are constantly exposed to different kinds of radiation originating from both natural sources and artificial manmade sources. Increasing the level of integration of electronic components and miniaturization trends may have negative influence onto the component sensitivity to ionizing radiation. Radiation defects can also occur in a process of a very large scale integrated circuits fabrication, since the process often includes bombardment with high-energy ions and photons,[1].

The radiation-induced defects refer to relatively stable lattice imperfections, produced by high-energy particles. Since single crystals are perfect bodies, their electrical and optical properties are strongly influenced by radiation-induced defects. Extensive studies on the influence of high-energy radiation on semiconductors have been carried out during the last fifteen years. Many of the investigations are concerned not only with general problems of semiconductor physics, but also with practical problems,[2].

1.2. Statement of The Problem

The research involved in this work discusses the Gamma radiation-induced defects in Silicon-based diodes. The experimental methods are used to investigate the impact The of Gamma particles on the threshold operating voltage.

1.3. Hypothesis of Research

During inelastic scattering on electrons, the incident particle can transfer energy to the atom, raising it to a higher energy level (excitation), or it may transfer enough energy to remove an electron from the atom (ionization). A portion of energy transferred during each individual scattering of heavy charged particles on electrons is small compared to an entire kinetic energy of a particle, but the number of particle collisions per a unit path length is as high that the entire total energy loss is significant even in relatively thin material layers.

1.4. Objectives of the Research

This work reviews the basic physical mechanisms of the interactions of ionizing radiation with Silicon-based diodes with respect to damage caused by Gamma ionization. The objectives of this thesis were, carrying out experimental measurements to evaluate the Direct Ionizing Radiation Damage.

1.5. Significance of the Research

The significance of the current study relies on its contribution to the efforts being done to develop a radiation-hardened electronics for devices working in radiation environment.

1.6. Limitations of the Study

The research involved in this study considers the impact of Gamma particles on the threshold operating voltage for Silicon-based diodes. Further study is required for the radiation-induced impacts on the optical and thermal properties of semiconductor components.

1.7. Methodology

A suitable Gamma emitter such as Cs-137 will be used to expose the silicon diode; to Gamma particles for a measured period of time. The electrical characteristics will be measured after irradiation and compared to that measured before irradiation.

CHAPTER TWO

RADIATION DAMAGE ON SEMICONDUCTORS

CHAPTER TWO

RADIATION DAMAGE ON SEMICONDUCTORS

2.1 Introduction

Exploring semiconductor lifetime, reliability and performance is a never-ending science for today's modern electronics. One significant problem that affects all of these areas is radiation-induced damage. Making calculations to determine how semiconductor devices will hold up in radiation-harsh environments has to be achieved in order to determine system lifetime once placed in their operational capacity. Today's high technology investments in such areas as satellite design, medical advances, military and commercial hardware, demand thorough understanding in radiation damage. Modeling semiconductor devices with computer-based simulation will provide a cost and time savings over a repetitive design and testing sequence. In this thesis we are interested in knowing how radiation can effect semiconductors performance, therefore we must know more about radiation.

2.2 Nature of Radiation

Radiation is energy that comes from a source and travels through space and may be able to penetrate various materials. Interestingly, there is a "background" of natural radiation everywhere in our environment. Ubiquitous background radiation comes from space (i.e., cosmic rays) and from naturally occurring radioactive materials contained in the earth and in living things.

There are two different kinds of radiation: Ionizing radiation, Non-ionizing radiation. Ionizing radiation is produced by unstable atoms which have an excess of energy, mass or both. Atoms with unstable nuclei are said to be radioactive.

In order to reach stability, these atoms give off, or emit, the excess energy or mass. These emissions are called radiation which can be delivered in form of electromagnetic waves (like light) or particulate (i.e., mass given off with the energy of motion), [3]. In this study we are more concerned about ionizing radiation because it is more energetic than non-ionizing radiation, and it has so much energy that it can knock electrons out of atoms.

2.3. Types of Ionizing Radiation

2.3.1. Alpha Particles

Alpha particles (α) are emitted by some unstable atoms .They are positively charged and made up of two protons and two neutrons from the atom's nucleus. Alpha particles come from the decay of the heaviest radioactive elements, such as uranium, radium and polonium. Even though alpha particles are very energetic, they are so heavy that they use up their energy over short distances and are unable to travel very far from the atom. The health effect from exposure to alpha particles depends greatly on how a person is exposed. Sketch diagram is shown in figure 2.1.

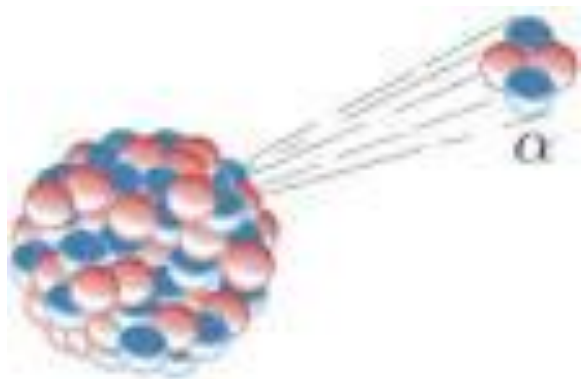

Fig 2.1, Sketch diagram for Alpha particle emission

2.3.2 Beta Particles :

Beta particles (β) are small, fast-moving particles with a negative electrical charge($^{-}\beta$-particles) or positive electrical charge ($^{+}\beta$-particles) that are emitted from an atom's nucleus during radioactive decay. These particles are emitted by certain unstable atoms such as hydrogen-3 (tritium), carbon-14 and strontium-90. Sketch diagram is shown in figure 2.2.

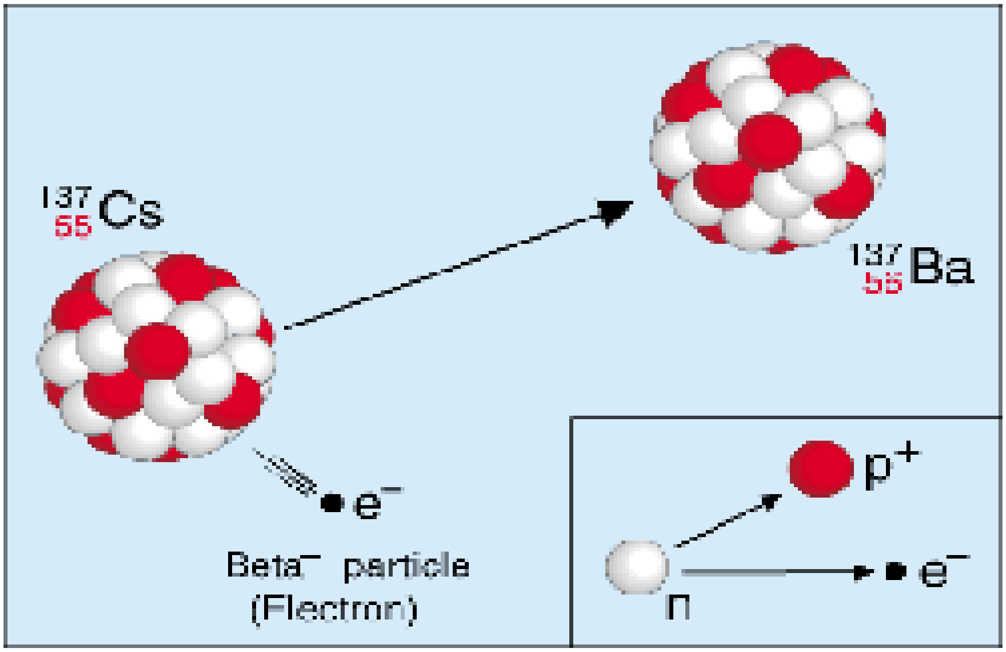

Fig 2.2.(a), Sketch diagram for Beta minus emission

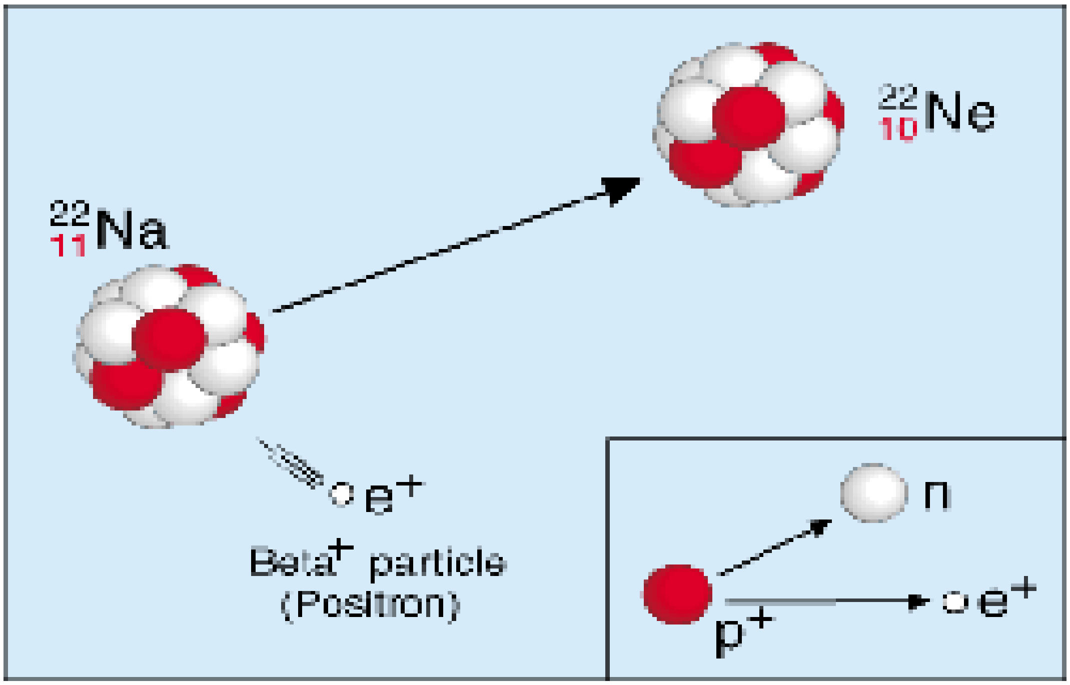

Fig 2.2.(b),Sketch diagram for positron emission

2.3.3 Gamma Rays :

Gamma rays are high-energy electromagnetic radiation emitted in the de excitation of the atomic nucleus,[4] . Unlike alpha and beta particles, which have both energy and mass, gamma rays are pure energy. They are similar to visible light, but have much higher energy. Gamma rays are classically produced by the decay from high energy states of atomic nuclei (gamma decay), but can also be created by other processes. Sketch diagram is shown in figure 2.3.

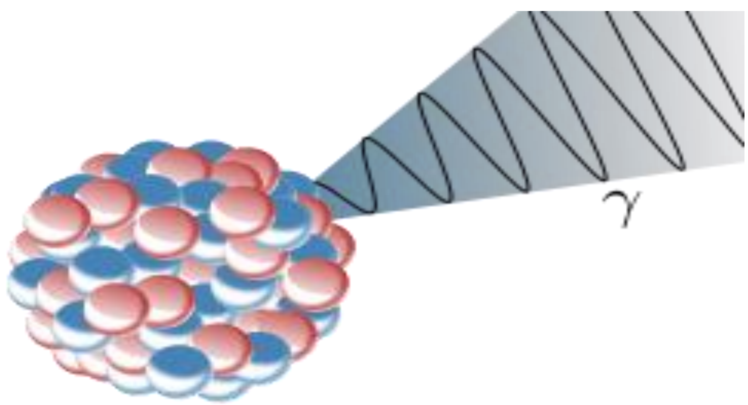

Fig 2.3, Sketch diagram for gamma emission

Gamma rays were first thought to be particles with mass, like alpha and beta rays. Rutherford initially believed they might be extremely fast beta particles, but their failure to be deflected by a magnetic field indicated they had no charge.

2.4 Sources of gamma ray

Natural sources of gamma rays on Earth include gamma decay from naturally occurring radioisotopes such as potassium-40, and also as a secondary radiation from various atmospheric interactions with cosmic ray particles. Some rare terrestrial natural sources that produce gamma rays that are not of a nuclear origin, are lightning strikes and terrestrial gamma-ray flashes, which produce high energy emissions from natural high-energy voltages. Gamma rays are also produced by a number of astronomical processes in which very high-energy electrons are produced. Such electrons produce secondary gamma rays by the mechanisms of bremsstrahlung, inverse Compton scattering and synchrotron radiation. Among the commonly used radioisotopes as gamma sources are; Co-60, Cs-137,[4].

2.5 Gamma interaction with matter

When a gamma ray passes through matter, the probability for absorption is proportional to the thickness of the layer, the density of the material, and the absorption cross section of the material. The total absorption shows an exponential decrease of intensity with distance from the incident surface;

$$I(x) = I_0 \cdot e^{-\mu x} \qquad (1.2)$$

where x is the distance from the incident surface. $\mu = n\sigma$ is the absorption coefficient, measured in cm^{-1}, n the number of atoms per cm^3 of the material (atomic density) and σ the absorption cross section in cm^2 ,[5]

2.6 Gamma Shielding

Shielding from gamma rays requires large amounts of mass, in contrast to alpha particles which can be blocked by paper or skin, and beta particles which can be shielded by foil. Gamma rays are better absorbed by materials with high atomic numbers and high density, although neither effect is important compared to the total mass per area in the path of the gamma ray. For this reason, a lead shield is only modestly better (20–30% better) as a gamma shield, than an equal mass of another shielding material such as aluminum, concrete, water or soil; lead's major advantage is not in lower weight, but rather its compactness due to its higher density. Protective clothing, goggles and respirators can protect from internal contact with or ingestion of alpha or beta emitting particles but provide no protection from gamma radiation from external sources. The higher the energy of the gamma rays, the thicker the shielding is required.

2.7 Radiation induced damage on semiconductors

Today's electronic devices operating in radiation harsh environments sustain radiation-induced damage that has a direct effect on system lifetime. Some of these defects affect the semiconductor lattice structure and therefore may alter device performance. The initial step towards beginning to understanding how radiation affects semiconductive devices is to first understand the device operation.

2.7.1 Basic Semiconductor Physics

A semiconductor is a material which has electrical conductivity between that of a conductor such as copper and that of an insulator such as glass.

Semiconductors are the foundation of modern electronics, including transistors, solar cells, diodes , quantum dots and digital and analog integrated circuits .
A pure semiconductor is a poor electrical conductor as a consequence of having just the right number of electrons to completely fill its valence bonds. Through various techniques (e.g., doping or gating), the semiconductor can be modified to have an excess of electrons (becoming an n-type semiconductor) or a deficiency of electrons (becoming a p-type semiconductor). In both cases, the semiconductor becomes much more conductive. Semiconductor devices exploit this effect to shape electrical current.

When doped semiconductors are joined to metals or to different semiconductors or to the same semiconductor with different doping, the resulting junction often strips the electron excess or deficiency out from the semiconductor near the junction. This depletion region is rectifying (only allowing current to flow in one direction), and used to further shape electrical currents in semiconductor devices, [6].

2.7.2 Energy levels

In the isolated atomic structure there are discrete energy levels associated with each orbiting electron. Each material will in fact have its own set of permissible energy levels for the electrons in its atomic structure. Between the discrete energy levels are gabs in which no electrons in the isolated atomic structure can appear, [7].

Electrons can be excited across the energy band gap of a semiconductor by various means. These electrons can carry their excess energy over distance scales of micrometers before dissipating their energy into heat–a significantly longer distance than is possible in metals.

This property is essential to the operation of, e. g., bipolar junction transistors and solar cells, [6]. Sketch diagram for energy levels is shown in fig 2.4

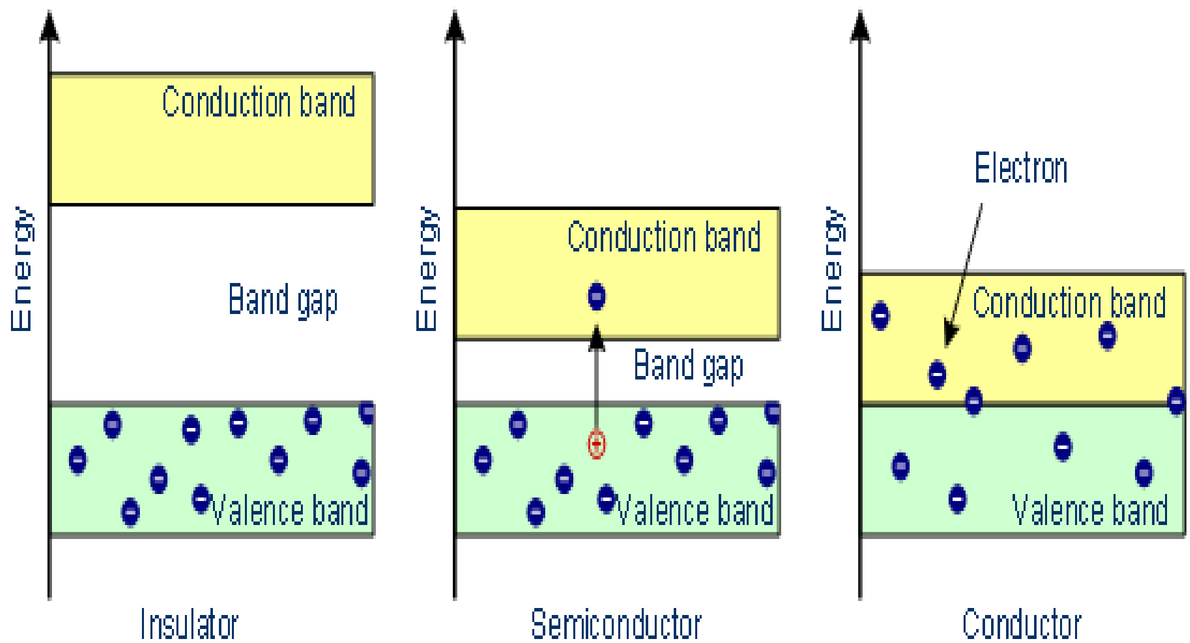

Fig 2.4, Sketch diagram for energy levels

There are different types of semiconductors devices, but in this study we are more interested in diodes because diodes are considered as a main component in a lot of electronic circuits .

A diode is an electrical device which allows current to move through it in one direction with far greater ease than in the other. The most common kind of diode in modern circuit design is the semiconductor diode, when placed in a simple battery-lamp circuit, the diode will either allow or prevent current through the lamp, depending on the polarity of the applied voltage. Sketch diagram is shown in fig 2.5

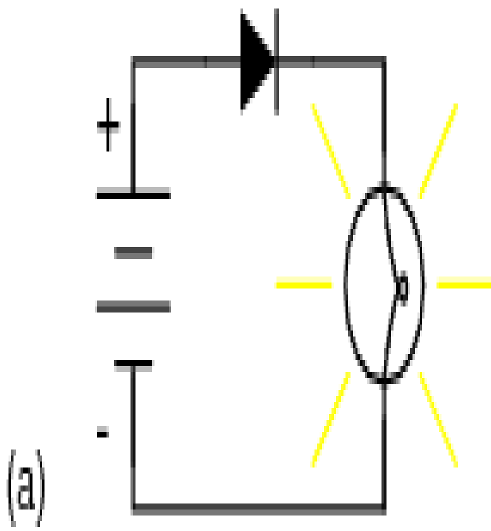

Fig 2.5 (a) Current flow is permitted; the diode is forward biased. (b) Current flow is prohibited; the diode is reversed biased.

When the polarity of the battery is such that electrons are allowed to flow through the diode, the diode is said to be forward-biased. Conversely, when the battery is “backward” and the diode blocks current, the diode is said to be reverse-biased. A diode may be thought of as like a switch: “closed” when forward-biased and “open” when reverse-biased. For silicon diodes, the typical forward voltage is 0.7 volts, nominal. For germanium diodes, the forward voltage is only 0.3 volts,[8]. Sketch diagram is shown in fig 2.6.

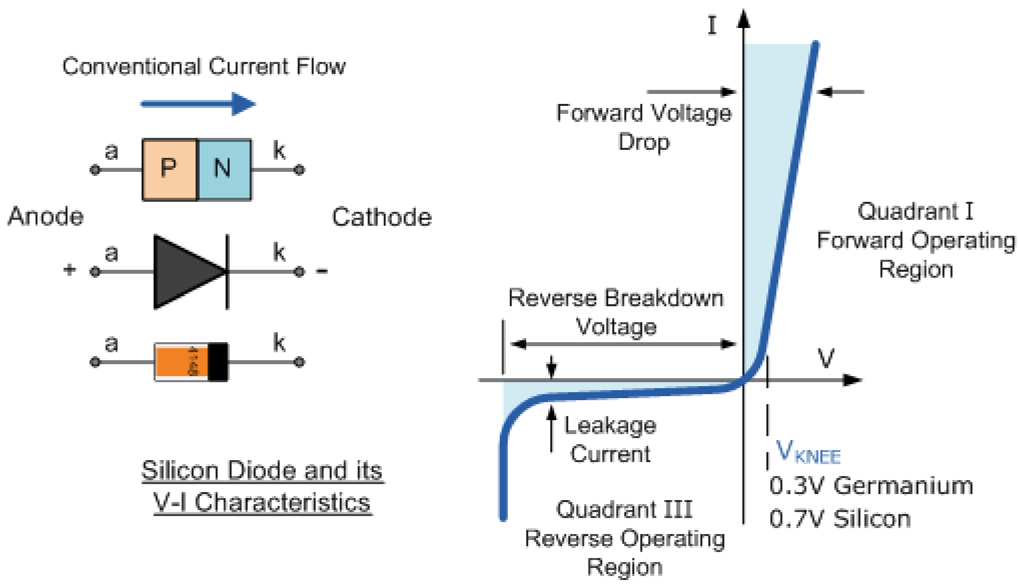

Fig 2.6 the operating voltage for Silicon and Germanium diodes

Radiation damage is the general alteration of the operational and detection properties of a detector, due to high doses of irradiation. In semiconductor devices, high-energy particles produce three main types of effects:

- **Displacements**. These are dislocations of atoms from their normal sites in the lattice, producing less ordered structures, with long term effects on semiconductor properties.
- **Transient ionization**. This effect produces electron-hole pairs; particle detection with semiconductors is based on this effect.
- **Long term ionization**. In insulators, the material does not return to its initial state, if the electrons and holes produced are fixed, and charged regions are induced.

Displacements determine the degradation of the bulk, and long term ionization is responsible for surface damage. Producing displacements is a four-step process:

- The primary particle hits an atom in the lattice, transferring enough energy to displace it. Thus, interstitials and vacancies appear, and their pairing - the so-called Frenkel defects. In the case of high energies, nuclear reactions can occur, producing several fragments or secondary particles.
- The fragments of the target atom migrate through the lattice causing further displacements. The mean free path between two successive collisions decreases towards the end of the range, so that defects produced are close enough and can interact.
- Thermally activated motion causes rearrangement of the lattice defects at room temperature (annealing). Parts of these rearrangements are influenced by the presence of impurities in the initial material.
- Thermally stable defects influence the semiconductor properties, i.e. also the detector parameters.

Effects of displacements are to be seen in the increase of capture, generation and recombination rates of the non-equilibrium charge carriers. In detectors they cause changes of the internal electric field, due to the modified doping concentration, going eventually up to inverting the conduction type for very high irradiations, increase of the leakage current, changes in capacitance and resistivity, and charge collection losses.

Long term ionization effects also comprise several steps:

- Ionization is produced along the track of the primary ionizing particle, or sometimes in restricted regions around a nuclear reaction. Electrons and holes are created, with a certain distribution.
- Many of the e-h pairs produced recombine before they could move due to diffusion or the electric drift. Recombination's take place between particles produced in the same or in different events.
- The electrons which did not recombine in the initial phase diffuse or drift away. Some electrons end up on traps, others may escape from the insulator.
- The carriers trapped on levels with low ionization energies are thermally re-excited and get into the conduction or valence band; they are subject to further drift or diffusion, and leave the dielectric or are captured on deep trap levels (practically permanent).
- Apart from the production of trapped charge, in the energy gap new oxide-silicon interface levels are induced. These interface states are occupied by electrons or holes, depending on the position of the Fermi level at the interface.
- The net effect of the induced charges in the oxide is the change of the electric field in the semiconductor, in the vicinity of the interface,[9].

In this work we studied the gamma – ray induced defect on Si because gamma is one of the constituents of cosmic radiation which seem to have great effect on electronic components .

2.8 Effect of Radiation on electronics

Radiation in space is generated by particles emitted from a variety of sources both within and beyond our solar system. Radiation effects from these particles can not only cause degradation, but can also cause failure of electronic and electrical system in space vehicles or satellites,[10] .Galactic cosmic rays are one of the most important barriers standing in the way of plans for interplanetary travel by crewed spacecraft; they also pose a threat to electronics placed aboard outgoing probes. In 2010, a malfunction aboard the Voyager 2 space probe was credited to a single flipped bit, probably caused by a cosmic ray,[11],[12].

CHAPTER THREE

EXPERIMENTAL PROCEDURE

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EXPERIMENTAL PROCEDURE

3.1 Introduction

Microelectronic devices and integrated circuits (ICs) can be exposed to a wide range of radiation environments. The types of particles, their energies, fluxes, and fluencies (or total dose) can vary considerably among the different radiation environments that electronics devices can be exposed to. These differences can lead to large variations in radiation-induced degradation. Moreover, devices that may be susceptible to radiation-induced degradation in one radiation environment may be robust in other radiation environments. The first step toward developing hardness assurance tests for a given radiation environment is to determine the nature of particles that electronic devices can be exposed to, [13].

Silicon diodes have been used in various fields, such as high energy physics, astrophysics, medical imaging and many industrial systems. There are various types of silicon sensors and most are based on the PIN or PN-junction diode [14]. Silicon sensors are used in tracking devices for high energy physics experiments and space sciences because of their high position resolution and material rigidity. Therefore, it is important to test the effects of radiation damage to the silicon diodes due to the susceptibility of the silicon sensor to radiation, [15]. This work measures the radiation induced changes in the electrical properties of 1A/1000V silicon diode 1N4007, [16].

The measurements were carried out for bar and shielded diode and the results were presented in terms of changes in its forward I-V characteristics resulting from the microscopic defects created by Cs-137 gamma irradiation. Portland cement powder was applied as a shielding layer to examine its performance in providing radiation hardness for 1N4007 silicon diode.

3.2 Radiation Damage In Silicon

It has been assumed that the radiation damage in silicon is proportional to the energy deposited into the displacement interactions (NIEL hypothesis), [17]. The displacement damage cross section D(Ep) expresses the relative displacement efficacy of an impinging particle p with energy Ep, taking into account the various type of interactions between the particle and the silicon atom. The displacement damage cross section is defined by,[18]:

$$D(E_P) = \sum_i \sigma_i(E_P) \int_{E_{R\min}}^{E_{R\max}} d\, E_R\, f_i(E_P, E_R) P(E_R) \qquad (3.1)$$

Where fi describes the distribution of the recoil atom with energy.

ER and P(ER) is the Lindhard partition function of the energy loss in non-ionizing processes by a recoiling nucleus of energy ER.

The lower bound of the integral corresponds to the minimum energy required to displace a silicon atom from the lattice and the upper limit is determined by the maximum energy transferred.

The gamma displacement cross-sections for energies up to 14 MeV have been calculated in various materials at two values of displacement threshold energy (24 and 40 eV), [19]. Three types of gamma ray interactions with materials were considered, the photoelectric effect, Compton scattering and pair production. Therefore, the total gamma displacement cross-section consists of three components representing the sum of cross-sections for three interactions;

$$\sigma_\gamma^T(E_\gamma) = \sigma_\gamma^{PE}(E_\gamma) + \sigma_\gamma^{CS}(E_\gamma) + \sigma_\gamma^{PP}(E_\gamma) \qquad (3.2)$$

Where Eγ is the gamma incident energy and the superscripts PE, CS, and PP represent photoelectric effect, Compton scattering, and pair production, respectively.

Using the data obtained in, [18], the total displacement damage cross section of silicon for photons is presented in Fig 3.1.

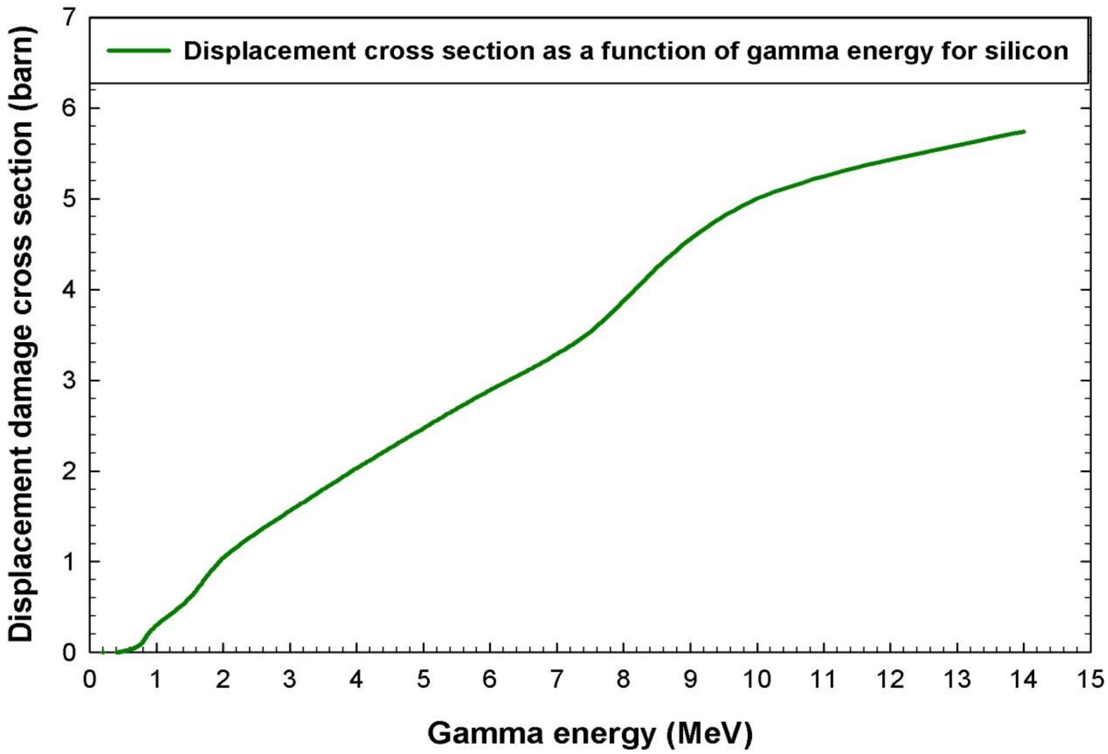

Figure 3.1. Displacement damage cross section as a function of gamma energy for silicon

Radiation-induced effects preventing is in increasing demand due to the increasing abundance and sensitivity of electronics. Gamma radiation shielding is based on the principle of attenuation, which is the ability to block or reduce the intensity of radiation through photoemission and scattering by a barrier material. Portland cement concrete has been known for decades as a polyphase composite material for the purpose of radiation shielding, [19].

In this work, Portland cement powder was used to form a thin layer cylindrically coating the 1N4007 silicon diode. This is to evaluate the performance of cement powder in shielding such electronic components against gamma photons.

3.3 Experimental Details

Irradiations with Cs-137 gamma were performed on 1N4007 silicon diode. Cs-137 source of activity 3.7 MBq was used in this work. The emissions of Cs-137 spectrums (I) as well as the background radiation (Io) were collected and analyzed using the gamma spectrometry system shown in Fig 3.2. It consists of a NaI(Tl) detector, high voltage power supply, preamplifier, amplifier multi channel analyzer and a computer with processing software to generate and display the spectra.

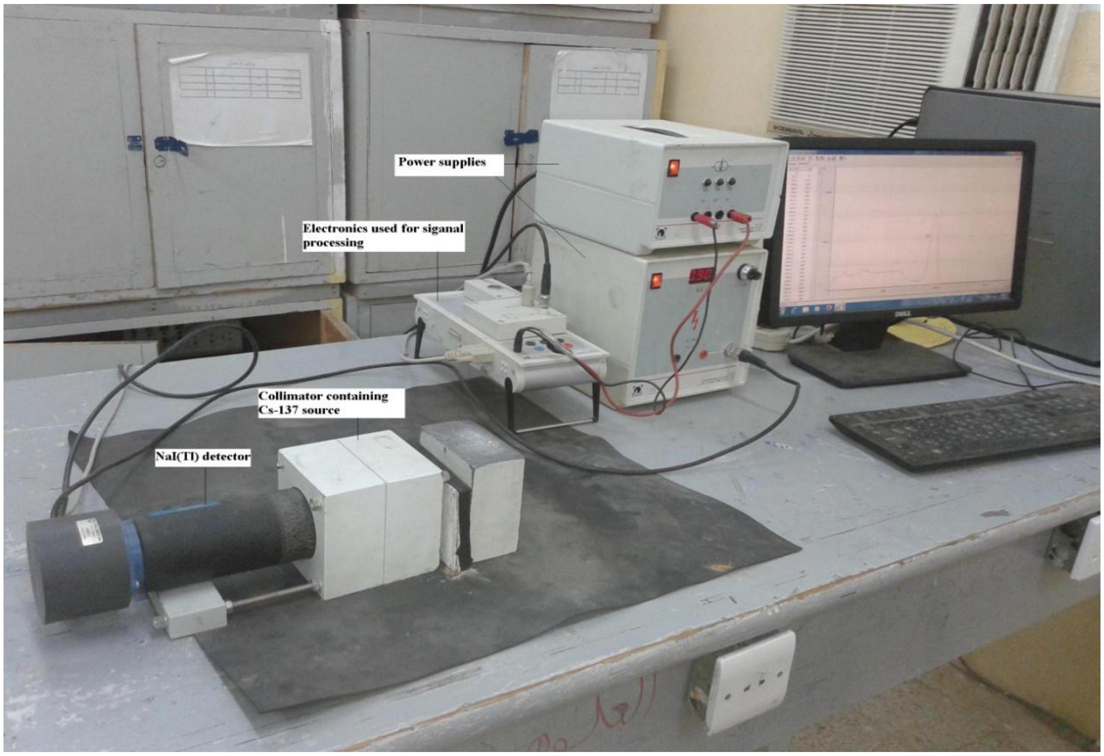

Figure 3.2. Gamma-ray spectrometry system used to produce Cs-137 net spectrum

The net spectrum (I-Io) Cs-137 is presented in Fig 3.3 showing that the Cs-137 source peaks at 662 Kev .

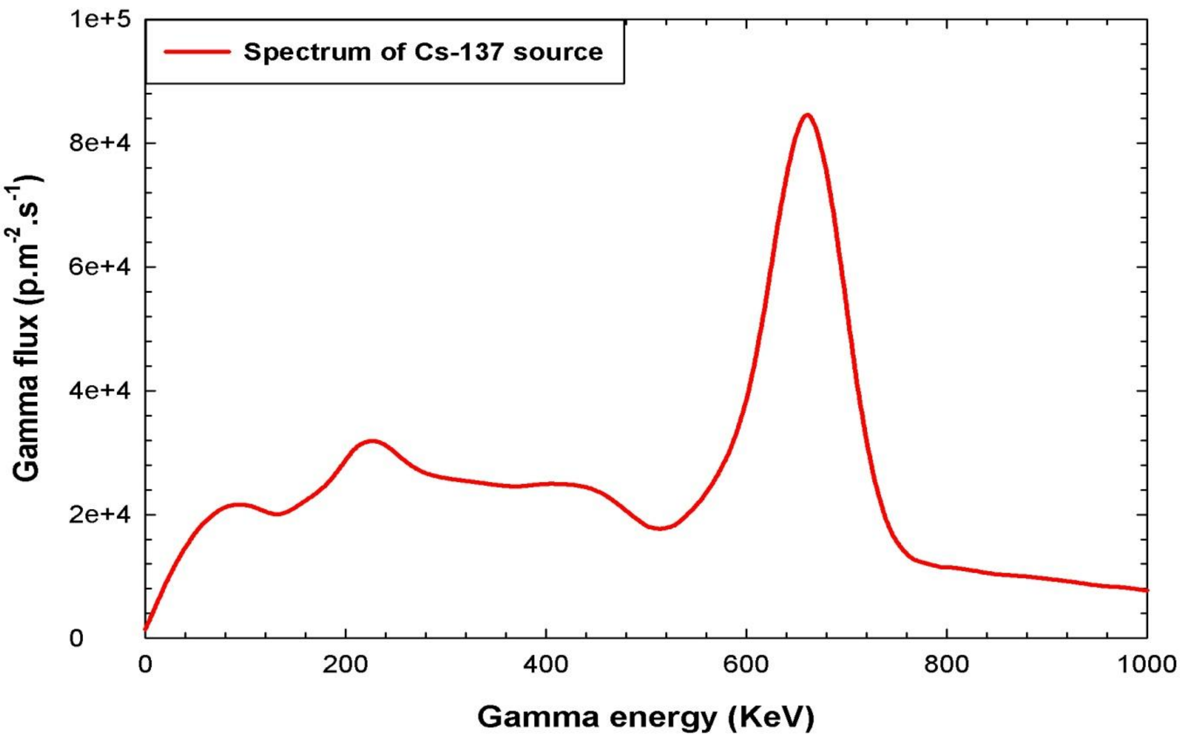

Figure 3.3 Net spectrum for the employed Cs-137 source

The electric circuit used in this experiment consists of a high voltage power supply, Rheostat, Ammeter, and a 1N4007 silicon diode all connected in series, and a Voltmeter connected in parallel with the silicon diode. The Ammeter and Voltmeter were scaled to measure current in (mA) and voltage in (V). And the Rheostat controls the current flowing in the circuit. The electrical circuit is shown in fig 3.4

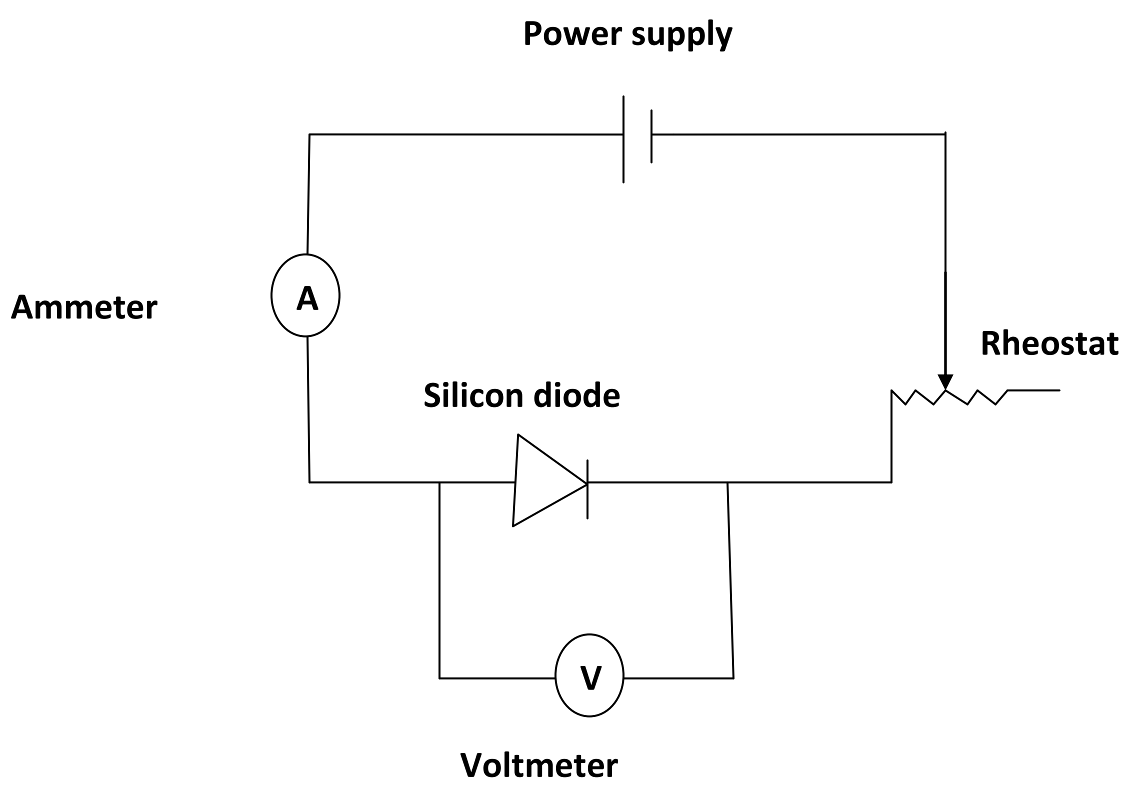

Fig 3.4 the electric circuit used to measure the effect of Cs-137 on Silicon diode

The measured forward I-V characteristics of the bar 1N4007 silicon diode were recorded for pre and post Cs-137 irradiating. The setup used is presented in Fig 3.5.

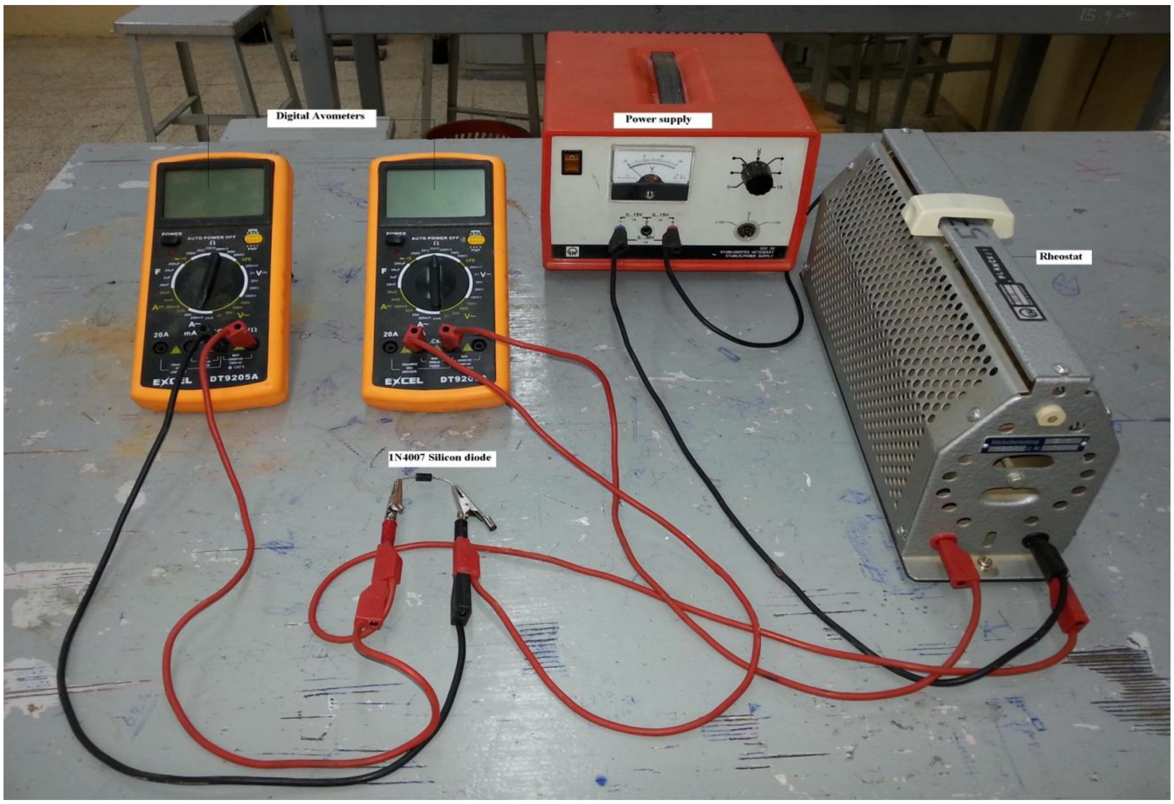

Figure 3.5 Setup for I-V measurements for pre irradiated 1N4007 silicon diode

To examine the possibility of shielding the 1N4007 diode against Cs-137 gamma, Portland powder cement was used to coat the diode cylindrically. The forward I-V characteristics for the shielded 1N4007 diode for radiation sources were recorded. For all measurements, the duration of exposure was adjusted to 5 minutes at room temperature.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Results and Discussions

The measured forward I-V characteristics of the bar 1N4007 silicon diode were recorded for pre and post Cs-137 irradiating. Table 4.1 shows the recorded results for the forward I-V characteristics of the bar silicon diode before irradiating.

Voltage (V)	Current (mA)
0.1400	0.0000
0.2600	0.0000
0.4400	0.0000
0.5100	0.3500
0.5800	1.6000
0.6400	6.2000
0.7000	21.2000
0.7300	40.7000
0.7500	69.8000
0.7700	106.6000

Table 4.1 The recorded results for the forward I-V characteristics of the bar silicon diode before irradiating.

Table 4.2 shows the recorded results for the forward I-V characteristics of the bar silicon diode after irradiating.

Voltage (V)	**Current (mA)**
0.1400	0.0000
0.2600	0.0000
0.4400	0.0000
0.5100	0.5000
0.5800	3.1000
0.6400	7.7000
0.7000	30.2000
0.7300	55.6000
0.7500	84.4000
0.7700	121.2000

Table 4.2 the recorded results for the forward I-V characteristics of the bar silicon diode after irradiating.

The forward current-voltage I-V measurements for pre and post irradiated bar 1N4007 silicon diode are presented in Fig 4.1 for Cs-137 gamma photons.

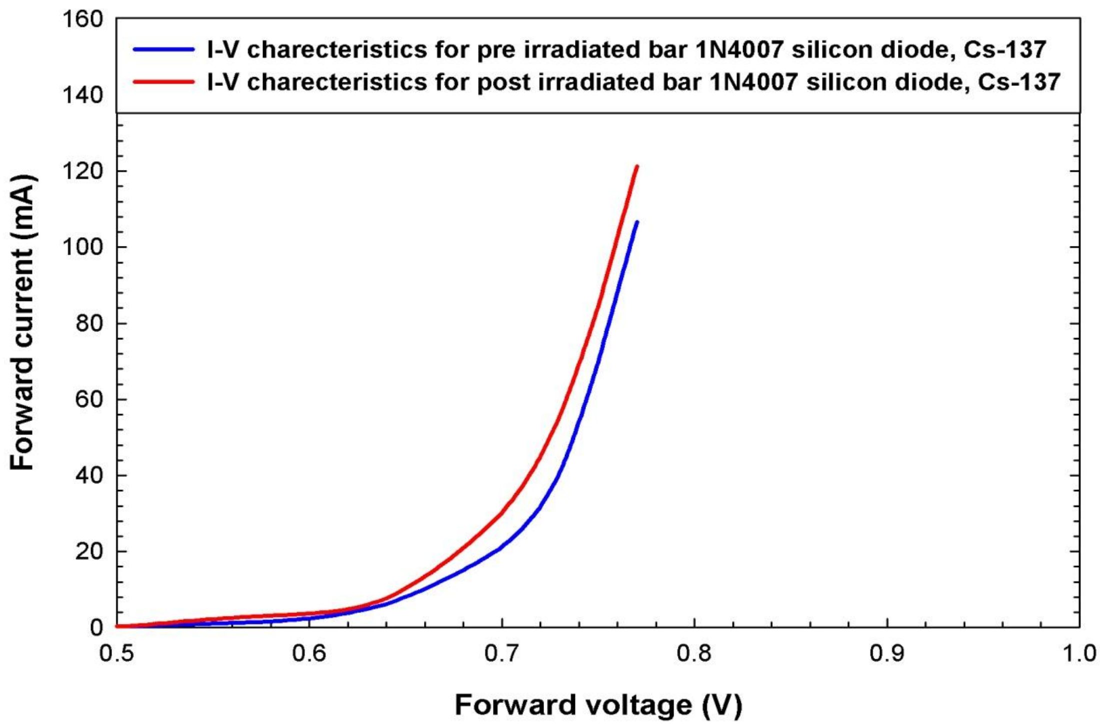

Figure 4.1. I-V characteristics for pre and post irradiated bar 1N4007 silicon diode, Cs-137

As shown, the radiation-induced effect appears in the significant increasing of forward current with respect to voltage. At 0.7V, the current increases by about 42% in case of Cs-137 gamma.

These results are reasonable since the displacement damage cross section for silicon is proportional to the incident photon energy.

On the other hand, I-V measurements for post irradiated shielded 1N4007 silicon diode are presented in table 4.3, for Cs-137 gamma.

Voltage (V)	**Current (mA)**
0.1400	0.0000
0.2600	0.0000
0.4400	0.0000
0.5100	0.3000
0.5800	1.4000
0.6400	4.2000
0.7000	18.6000
0.7300	35.8000
0.7500	59.1000
0.7700	98.4000

Table 4.3 I-V measurements for post irradiated shielded 1N4007 silicon diode

The I-V characteristics for irradiated shielded 1N4007 silicon diode compared to that of pre and post irradiated bar 1N4007 silicon diode, is shown in fig 4.2

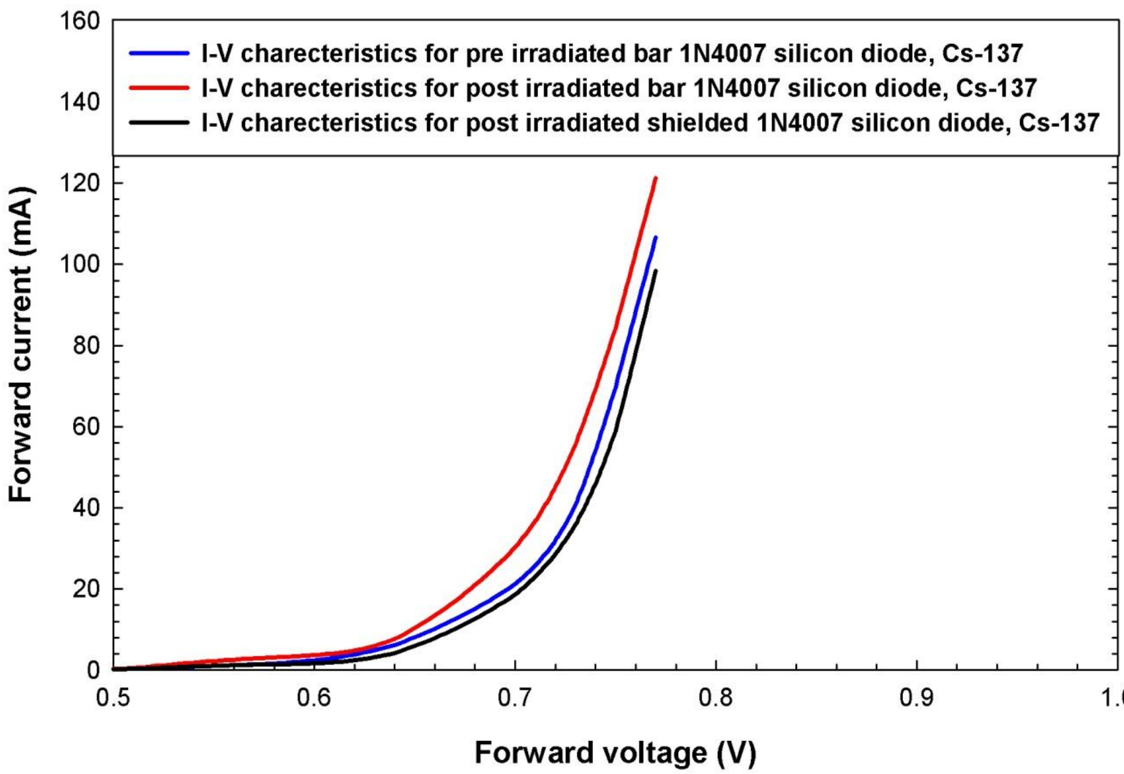

Figure 4.2 .I-V characteristics for irradiated shielded 1N4007 silicon diode compared to that of pre and post irradiated bar 1N4007 silicon diode, Cs-137

As shown, in comparison with current values (I) for pre and post irradiated 1N4007 diode , the presence of cement coating shield has shifted the current values (I) to near normal regions (values of I for pre irradiated 1N4007 silicon diode) and thus limited the radiation-induced effects for the employed source. This was confirmed by the reduction of current values (I) by about 38% for Cs-137 gamma.

It is worth mentioning that the cement coating shield has shifted the forward current values (I) below that of pre irradiated 1N4007 diode. This may be attributed to the effect of background radiation, suggesting that the targeted diode has already exposed to background radiation before being irradiated by Cs-137 gamma. These findings confirm the efficiency of the applied cement coating shield.

4.2 Conclusions

The experimental results confirmed that the electrical properties of 1N4007 silicon diode in terms of I-V characteristics were strongly affected by γ irradiation. The results also revealed the dependency of the I-V characteristics on the type and energy of the incident radiation. In addition, the results indicated that the degradation of the 1N4007 silicon diode properties might be attributed to the introduction of radiation-induced lattice defects by displacement damage.

The proposed cement powder shield has significantly reduced the radiation-induced damage and approved the possibility of hardening electronics against gamma photons. Further investigations are required on the practicality of using cement-based coatings to shield electronics at different energy ranges of gamma photons.

4.3 Recommendations

The current experimental results suggest further research considering cosmic-like environment to address the radiation-induced effects of different types of radiation and to predict the suitable shielding materials. This is to explore the possibility of producing radiation hardened (Rad-Hard) electronic devices.

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