Effects of Cs-137 Gamma and X-Ray Irradiation on the Electrical Characteristics of Silicon Diode 1N4007

N. Elsheikh
Center of Alternative Energies and Sustainable Development, Omdurman Ahlia University, Omdurman, Sudan
Email: nassreldeen.elsheikh@yahoo.com

F. Saboun
Department of Physics, Sudan University of Science and Technology, Khartoum, Sudan
Email: farah.saboun@hotmail.com

***Abstract*—Experiments were carried out to study the Cs-137 gamma and X-ray induced defects in bar and shielded 1N4007 silicon diode. Cs-137 gamma-ray source and X-ray 5548 RÖNTGENGERAT APPARATUS were utilized in this work. The current-voltage (I-V) characteristics for pre and post irradiated bar and shielded 1N4007 silicon diode were recorded. In addition, the impact of Portland cement as a shielding layer was investigated. For both type of sources used, results confirmed the dependency of I-V characteristics on the type and energy of the irradiating source. On the other hand, for both sources, the presence of cement coating shield has significantly reduced the radiation-induced damage in 1N4007 silicon diode since it has shifted the I-V characteristics to near standard operating conditions (I-V characteristics for pre irradiated 1N4007 silicon diode) and approved the possibility of hardening electronics against gamma and X-ray photons.**

***Index Terms*—Cs-137 gamma source, radiation-induced defects, silicon diode 1N4007, X-rays**

I. 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 [1].

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 [2]. 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 [3].

This work measures the radiation induced changes in the electrical properties of 1A/1000V silicon diode 1N4007 [4]. 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 and X- ray irradiation. Portland cement powder was applied as a shielding layer to examine its performance in providing radiation hardness for 1N4007 silicon diode.

II. 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) [5]. The displacement damage cross section $D(E_p)$ expresses the relative displacement efficacy of an impinging particle p with energy E_p, taking into account the various type of interactions between the particle and the silicon atom. The displacement damage cross section is defined by [6]:

$$D(E_P) = \sum_i \sigma_i(E_P) \int_{E_{R\min}}^{E_{R\max}} d\,E_R\, f_i(E_P, E_R) P(E_R) \qquad (1)$$

The function f_i describes the distribution of the recoil atom with energy E_R and $P(E_R)$ is the Lindhard partition function of the energy loss in non-ionizing processes by a recoiling nucleus of energy E_R. 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 14MeV have been calculated in various materials at two values of displacement threshold energy (24 and 40eV) [7]. Three types of gamma ray interactions with

Manuscript received July 30, 2014; revised December 26, 2014.

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;

$$\sigma_\gamma^T(E_\gamma)=\sigma_\gamma^{PE}(E_\gamma)+\sigma_\gamma^{CS}(E_\gamma)+\sigma_\gamma^{PP}(E_\gamma) \qquad (2)$$

where E_γ 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 [7], the total displacement damage cross section of silicon for photons is presented in Fig. 2.1.

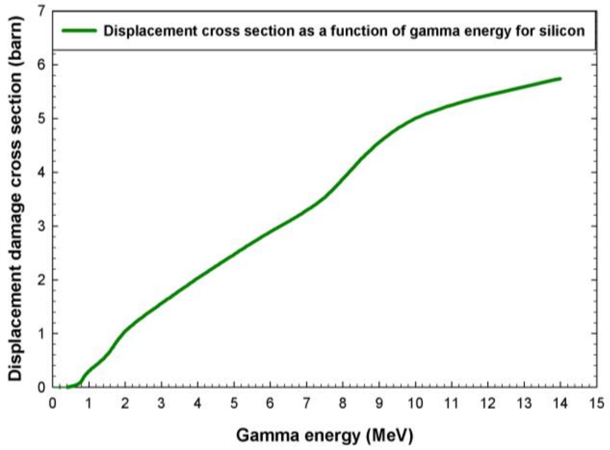

Figure 2.1. Displacement damage cross section as a function of gamma energy for silicon

Radiation-Induced effects preventing is in increasing demand due to the increasing abundance and sensitivity of electronics. Gamma and X-ray 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 [8]. 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 and x-ray photons. The major mineral constituents of the utilized Portland cement powder with their normalized mass fractions are presented in Table I.

TABLE I. THE MAJOR MINERAL CONSTITUENTS OF PORTLAND CEMENT POWDER USED

Compound	Chemical Formula	Mass Fraction
Tricalcium Silicate	Ca_3SiO_5	0.6651
Dicalcium Silicate	Ca_2SiO_4	0.1961
Tricalcium Aluminate	$Ca_3Al_2O_6$	0.0258
Tetracalcium Aluminoferrite	Ca_2AlFeO_5	0.1130

III. EXPERIMENTAL DETAILS

Irradiations with gamma-ray and X-ray photons were performed on 1N4007 silicon diode. In this work, Cs-137 source of activity 3.7MBq was employed as the source of gamma-ray photons. While the fully assembled X-ray 5548 RÖNTGENGERAT APPARATUS shown in Fig. 3.1, was employed as the source of X-ray photons.

Figure 3.1. X-ray 5548 Röntgengerat apparatus

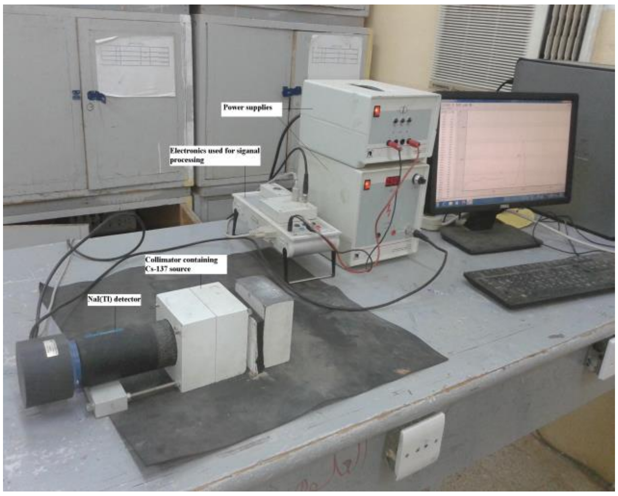

Figure 3.2. Gamma-ray spectrometry system used to produce Cs-137 net spectrum

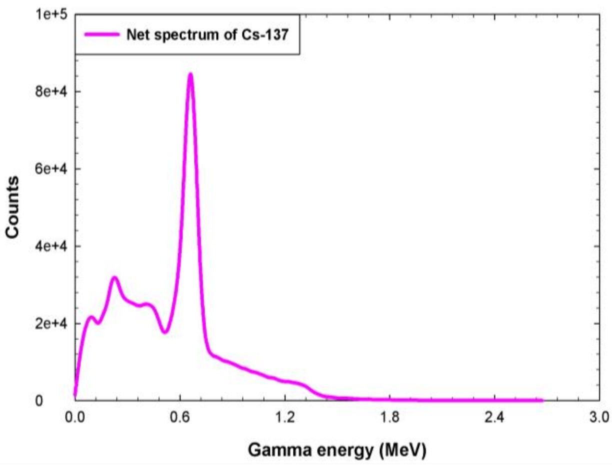

Figure 3.3. Net spectrum for the employed Cs-137 source

The emissions of Cs-137 spectrums (I) as well as the background radiation (I_o) 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. The net spectrum ($I-I_o$) Cs-137 is presented in Fig. 3.3.

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. Schematic diagram of the electrical circuit is shown in Fig 3.4.

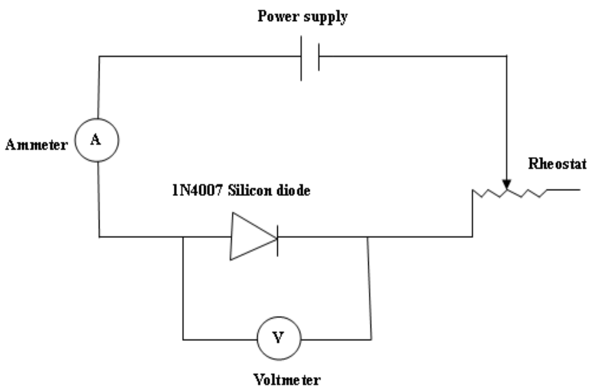

Figure 3.4. Schematic diagram for the electric circuit used to measure the effect of Cs-137 on Silicon diode

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

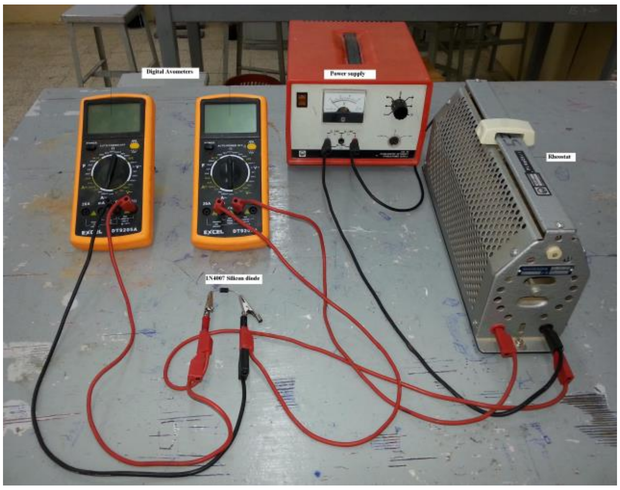

Figure 3.5. Setup for I-V measurements for pre irradiated 1N4007 silicon diode

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

IV. Results and Discussions

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 and Fig. 4.2 for X-ray photons.

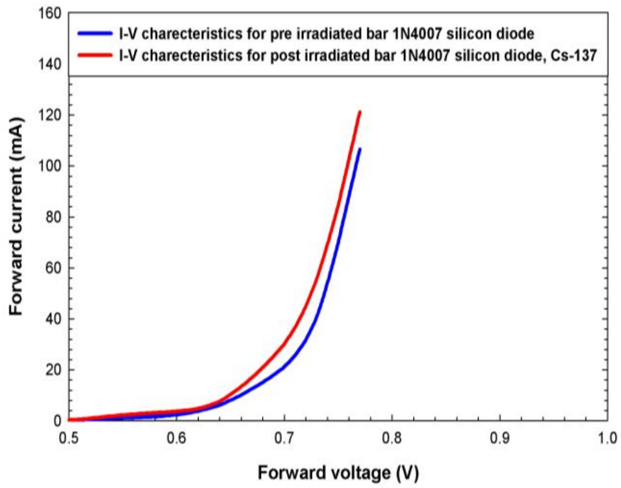

Figure 4.1. I-V characteristics for pre and post irradiated bar 1N4007 silicon diode, Cs-137

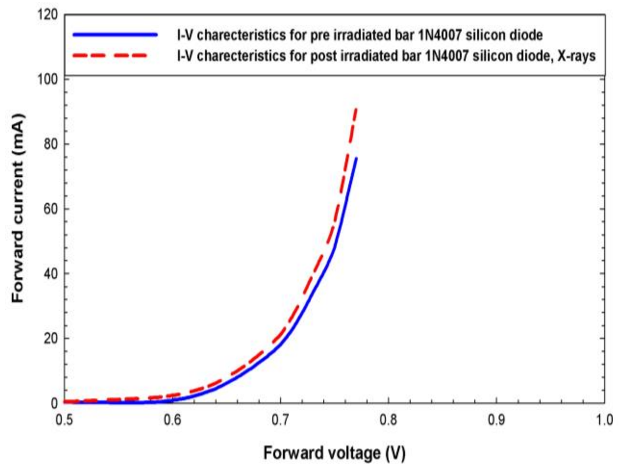

Figure 4.2. I-V characteristics for pre and post irradiated bar 1N4007 silicon diode, X-rays

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 49% and 17% in case of Cs-137 gamma and X-ray photons, respectively. These results are reasonable since the displacement damage cross section for silicon is proportional to the incident photon energy. The spectrum of the utilized Cs-137 peaks at 16.5 MeV while the X-ray apparatus was adjusted to generate photons of 20KeV.

On the other hand, I-V measurements for post irradiated shielded 1N4007 silicon diode are presented in Fig. 4.3, for Cs-137 gamma and Fig. 4.4, for X-ray photons.

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 both employed sources. This was confirmed by the reduction of current values (I) by about 38% and 22% for Cs-137 gamma and X-ray photons, respectively.

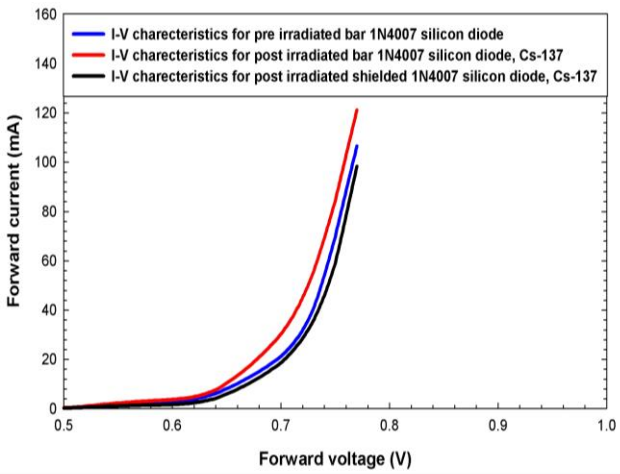

Figure 4.3. I-V characteristics for irradiated shielded 1N4007 silicon diode compared to that of pre and post irradiated bar 1N4007 silicon diode, Cs-137

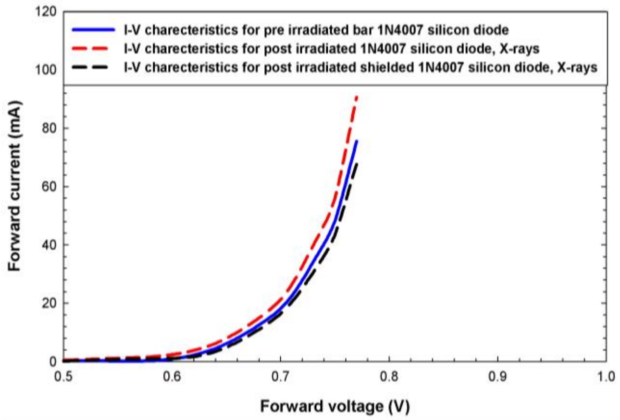

Figure 4.4. I-V characteristics for irradiated shielded 1N4007 silicon diode compared to that of pre and post irradiated bar 1N4007 silicon diode, X-rays

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 or X-ray photons. These findings confirm the efficiency of the applied cement coating shield.

V. Conclusion

The experimental results confirmed that the electrical properties of 1N4007 silicon diode in terms of I-V characteristics were strongly affected by γ and x-ray 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 and X-ray photons. Further investigations are required on the practicality of using cement-based coatings to shield electronics at different energy ranges of gamma and X-ray photons.

Acknowledgement

The authors wish to thank the technicians at the Physics laboratory hosted in the department of Physics, Sudan University of Science &Technology.

References

[1] J. R. Schwank, M. R. Shaneyfelt, and P. E. Dodd, "Radiation hardness assurance testing of microelectronic devices and integrated circuits: Radiation environments, physical mechanisms, and foundations for hardness assurance," *Sandia National Laboratories Document*, *SAND*, 2008.

[2] H. G. Nam, M. S. Shin, K. H. Cha, N. I. Cho, and E. J. Yun, "Fabrication of a silicon PIN diode for radiation detection," *Journal of the Korean Physical Society*, vol. 48, no. 6, pp. 1514-1519, Jun. 2006.

[3] J. Lee, D. H. Kah, H. J. Kim, H. B. Park, and J. H. So, "Radiation hardness study for silicon strip sensors using the 35-MeV proton beam from the MC-50 cyclotron at the Korea institute of radiological and medical sciences," *Journal of the Korean Physical Society*, vol. 48, no. 4, pp. 850-854, Apr. 2006.

[4] Diodes. [Online]. Available: http://www.diodes.com/

[5] H. J. Hyun, *et al.*, "Radiation damage study of AC-coupled silicon strip sensors with a proton beam," *Journal of the Korean Physical Society*, vol. 50, no. 5, pp. 1548-1551, May 2007.

[6] A. V. Ginneken, "Non-Ionising energy deposition in silicon for radiation damage studies," Fermilab National Accelerator Laboratory FN-522, Oct. 1989.

[7] J. Kwon and A. T. Motta, "Gamma displacement cross-sections in various materials," *Annals of Nuclear Energy*, vol. 27, no. 18, pp. 1627-1642, 2000.

[8] H. Guan, S. Liu, Y. Duan, and J. Chen, "Cement based electromagnetic shielding and absorbing building materials," *Cement and Concrete Composites*, vol. 28, no. 5, pp. 468-474, 2006.

N. Elshiekh received his Ph.D. in the Faculty of Applied & Industrial Sciences from department of Physics, University of Juba, Juba, South Sudan in 2012. He is currently working as Assistant Professor in the Center of Alternative Energies& Sustainable Development, Omdurman Ahlia University, Sudan. His research interests include applications of radioisotopes in nuclear nondestructive detection systems, radiation-induced defects in semiconductors.

F. Saboun received his M.Sc in Radiation Protection from Sudan Academy of Sciences, Sudan. He is currently pursuing his PhD in radiation-induced effects in solar cells. His research interests include modeling of radiation shielding systems and irradiation defects in the electronics.