Research article

Effect of Gamma Radiation on Characteristic of bipolar junction Transistors (BJT_s)

Abdenabi Ali.Elamin¹, Wael H. Alawad²

¹Department of Physics, Faculty of Science and Technology, Omdurman Islamic University -

² Omdurman Islamic University-Faculty of Engineering Science

ABSTRACT

This paper describes the effects of ⁶⁰Cogamma radiation hardness of characteristic and parameters of Bipolar Junction Transistors in order to analyze the performance changes of the individual devices used in nuclear field. Bipolar Junction Transistor (BJT) of the type (BC-301) (npn) silicon, Transistor was irradiated by gamma radiation using ⁶⁰Cosource at different doses (1, 2, 3, 4, and 5) KGy. The characteristics and parameter of Bipolar Junction Transistor was studied before and after irradiated by using Transistor Characteristics Apparatus with regulated power supplies. Obtained result showed that, the saturation voltage $V_{CE(sat)}$ of Bipolar Junction Transistor decreased because of the gain degradation of the transistor and increased silicon resistivity, Another parameter of a bipolar junction transistor affected by ionizing radiation is a collector-base leakage current, a strong increase of the current is caused by the build-up charge near the junction.

1. Introduction

The transistor was invented by a team of three men at Bell Laboratories in 1947. Although this first transistor was noted a bipolar junction device, it was beginning of a technological revolution that is still continuing. All of the complex electronic devices and systems today are an outgrowth of early developments in semiconductor transistors.

Two basic types of transistors are the bipolar junction transistor (BJT), which we will begin to study in this paper, and the field effect transistor (FET). The BJT is used in two broad areas as a linear

amplifier to boost or amplify an electrical signal and as an electronic switch.

Transistors can be used as amplifiers in nuclear field such as radiation counters devices (Barboottin and Vapaille 1999).

In the last few years a great deal of work has been done on the effects of gamma rays, neutrons, carbon ions, and electron beam on Field Effect Transistors (FET), and Bipolar Junction Transistors (BJT) of Jorio et al 1998. However, very little interest was directed to the effects of gamma rays on characteristics and parameters of Bipolar Junction Transistors. Gamma radiation is one of the three types of natural radioactivity. Gamma rays are

electromagnetic radiation, like X-rays. The other two types of natural radioactivity are alpha and beta radiation, which are in the form of particles. Gamma rays are the most energetic form of electromagnetic radiation, with a very short wavelength of less than one-tenth of a nanometer (Maessenger and Ash 1986). Gamma radiation is the product of radioactive atoms. Depending upon the ratio of neutrons to protons within its nucleus, an isotope of a particular element may be stable or unstable. When the binding energy is not strong enough to hold the nucleus of an atom together, the atom is said to be unstable. Atoms with unstable nuclei are constantly changing as a result of the imbalance of energy within the nucleus. Over time, the nuclei of unstable isotopes spontaneously disintegrate, or transform, in a process known as radioactive decay. Various types of penetrating radiation may be emitted from the nucleus and/or its surrounding electrons. Nuclides which undergo radioactive decay are called radionuclide. Any material which contains measurable

amounts of one or more radionuclide's is a radioactive material (Maessenger and Ash 1986).

Radiation effect on Bipolar Junction Transistors may be degradation of transistors parameters during irradiation is due to both the structural damage in the crystal lattice and changes surface properties of the crystal. Photons and particles in a form of radiation can basically generate two different types of effects on transistors components:

- ionizing effect.
- Displacement damage (Adams and Holmes-siedle 2004).

Therefore, radiation can modify electrical parameters of the device, deteriorate its characteristics and finally lead to the functional failure of the components or the whole system. Moreover, ionizing particles can produce photocurrent in active regions of devices and provoke upsets, called single event effects (SEEs). The influence of gamma radiation on electronic components with the emphasized interactions are depicted in table 1.1

Table 1. gamma radiation effects on electronic components by Giustino (2001).

Radiation	Energy Range	Main type of Interaction	Primary Effects	Secondary Effects
Photons	Low Energy	Photoelectric Effect	Ionizing phenomenon	Displacement damage
	Medium Energy	Compton Effect		
	High Energy	Pair production		

High energy incident particles can interact with nucleus, assuming that the incident particle has matter mainly in three different ways: enough energy.

1. Ionization of the latter through the interaction
2. Displacement of atoms
3. Nuclear reaction with the target nucleus with shell electrons. (Vitusevich et al 2003).

Gamma-ray photons deposit energy in the components mainly by ionization (Devine 1994) the energy used for ionizing phenomenon is called the ionizing dose. The ionizing effect can be caused by different kind of ionizing radiation e.g gamma, x-ray, ultra-violet radiation (Lee et al; 2012). The principal ionizing-based damage effects in a bulk material are enhancement of conductivity through production of excess charge carriers, trapped charge, electric and magnetic fields and chemical effects by Devine 1994, the phenomena connected with the increased conductivity of silicon. Photons interact with matter, depending on their energy, in at least three different ways (Wrobel 2005), (Lee et al 2012).

1. photoelectric effect
2. the Compton effect
3. electron-positron pairs production

Photovoltaic effect is triggered by low energy photons, like x-ray, the Compton effect and pairs production occur for higher-energy photons like gamma radiation (Tal et al 2011). Free electrons produced during ionizing damage, which have enough energy, span to the forbidden gap and created electron-hole pairs, therefore, the conductivity of the bulk material is temporarily enhanced. Incident gamma radiation produces electron-hole pairs, a fraction of generated pairs quickly recombines with other carriers, the electrons mobility is much higher than holes. The second effect concerns the rearrangement of the atomic bonds at interface and production of new interface states (Fleetwood 2005). The trapped charge and created anomalies have a significant influence on the electrical properties of electronic components.

Charge trapping centres created during the irradiation affects negatively parameters of the bipolar transistor, firstly recombination centers are responsible for decreasing of the minority carriers life time of Wrobel (2005). Accordingly minority carriers life time damage coefficient k_t can be expressed by equation (1.1).

$$\Delta (1/t) = 1/t_1 - 1/t_0 = k_t \cdot \Phi \quad (1.1)$$

Where t_0 is the minority carriers lifetime before the irradiation, t_1 being the minority carriers after irradiation and Φ corresponds to the particle fluence. The common-emitter current gain β (h_{FE}) of the transistor will be decreased according to equation (1.2).

$$\Delta (1/h_{FE}) = \frac{1}{2} W_B^2 / D_{pB} \cdot k_t \cdot \Phi = k_{hFE} \cdot \Phi$$

Where W_B^2 is the base width of bipolar junction transistor, D_{pB} is the diffusion coefficient of hole within the base. The gain degradation is therefore proportional to the particle fluence during the irradiation and the damage coefficient associated with carrier's lifetime k_{hFE} (Fleetwood 2005), (Chmielewski and Haji-Saeid, 2004), (Fair and 2002). According to equation 1.2, transistor exposed to radiation should operate in the region with a narrow base width therefore; high-frequency transistors opt to be more radiation resistant. Moreover, degradation depends on the collector current and as result of this, is lower for high collector currents, the gain degradation for npn transistor. Another parameter of a bipolar junction transistor affected by ionizing radiation is a collector-base leakage current; a strong increase of the current is caused by the build-up charge near the junction (Burke and James 199).

2. Materials and Methods

Experimental measurement in this paper was carried out on the commercially available transistors devices. In this experiment the following were measured:

(1) Input Characteristics between V_{BE} volt and I_B current value was measured, at $V_{CC}=(3, 6, 9)$ volt were constant for each volts.

(2) Output Characteristics, the I_B current value was sitting up at (50 μA) due to changing of V_{CC} value, the I_C current value for V_{CC} value was teacked, the relationship between V_{CE} and I_C value was measured, so the I_B current value was changed to (150 μA) and the experiment was repeated, then the curve was bean done according to the preface curve.

Transistors were irradiated with ^{60}Co gamma source with doses (1, 3and 5 KGY), the energy of 1.25MeV, and half lifetimeof 2.27 years,the dose rate was 100Gy/h. (this energy sufficient for creation of electron –hole pairsbyTal et al

2011). Irradiation was performed through glass in controlled environment. The transistors were irradiated in air at room temperature 27⁰C (Vitusevich et al 2003).

Before and after the irradiation current – voltage (I-V) characteristics were measured in highly controlled condition at room temperature. Two measurements of the (I-V)characteristics have been under taken:

- (1) First measurement: immediately before gamma irradiation.
- (2) Second measurement: immediately after gamma irradiation.

3. Results and Discussion

The results in figures (1,2 and 3.) had been obtained from out characteristics (I_C - V_{CE}) curve for transistor of the type (BC-301) (NPN) before and after irradiation by gamma rays with different dose (1, 3 and 5) KGY. The I_C vs V_{CE} curve was measured with different I_B current (50, 150 and 250) μA before and after irradiated.

Fig 2. : The relationship between I_C (mA) and V_{CE} (volt) before and after irradiation by gamma rays at (3KGy)

Fig 3. The relationship between I_C (mA) and V_{CE} (volt) before and after Irradiation by gamma rays at (5KGy)

From these figures it is clear that the I_C decrease when the total irradiation dose of gamma rays increases for each the I_B constant current (50 μA , 150 μA and 250 μA).

For transistor (BC-301) (NPN) which was exposed to gamma rays, this decrease of I_C current is due to produces electron-hole pairs, a fraction of generated pairs quickly recombines with other carriers, the electrons mobility is much higher than holes of Aktas and Kuliev (2004). This decrease was attributed to decrease of

the emitter efficiency of transistor as shown in fig7, and described equation (1.2). This result obtained in this paper as same direction by Dariusz et al (2013).

For effects of irradiation on input characteristics of (BJT) and from results in figures (1, 2 and 3) had been obtained from the transistors before and after irradiation by gamma rays with different dose (1, 3 and 5) KGy. The (I_B - V_{BE}) curve was measured with different V_{CC} (0, 3 and 6) volt.

Fig 4 The relationship between I_B (mA) and V_{BE} (volt) before and after irradiation by gamma rays at (1K Gy)

Fig 5 The relationship between I_B (mA) and V_{BE} (volt) before and after irradiation by gamma rays at (3K Gy)

From figures 4,5 and 6 it is clear that the I_B increase when the total irradiation dose of gamma rays increases and the V_{CC} constant at (0, 3 and 6) volt.

This increase of I_B was attributed to radiation should operated in the region

with base width due to increase minority carriers life time of p-type of NPN transistor which is described in equation (1.1) and (1.2).

Fig 6. The relationship between I_B (mA) and V_{BE} (volt) before and after irradiation by gamma rays at (5KGy)

For the changes of the emitter efficiency of transistor (β_{DC}) due to irradiation was performed on the five transistors (BC-301) (NPN) and their forward current gain factor (hFE) or β_{DC} were calculated before and after irradiation changes is shown in fig.7 where β_{DC} is shown to be seriously affected by gamma dose, for all

the transistors, the β_{DC} was decreased from their initial value is 60 (before irradiation), depending on the absorbed dose of (1, 2, 3, 4, and 5) KGy respectively. The radiation damage effects as a function of the operating current during measurements of the forward current gain changes.

fig 7. The relationship between B_{DC} and Gamma Dose (KGy)

By analysis the data in fig.7 of the change in the emitter efficiency of transistor (β_{DC}) and the total irradiation dose for transistors (BC-301) (NPN) it was possible to set equation that can define the relationship between the absorbed dose and the emitter efficiency of transistor (β_{DC}) as follows in eq.(3.1). This equation can be used as a counter to detect the gamma rays.

$$Y = 26.17 + 51.26 e^{\frac{-x}{1.157}} \quad (3.1)$$

Where x is total absorbed dose of Gamma ray which emits from ^{60}Co and Y is the emitter efficiency of transistor (β_{DC})

4. Conclusion

The impact of gamma radiation on the transistors have been studied it is found through experiments that there is a change in characteristics and parameter of Bipolar Junction Transistor due to gamma rays depending on the amount of dose and type of interaction between radiation and materials exposed.

The effects of gamma rays on Bipolar Junction Transistor dependent of type of radiation, type of transistor, type of interaction and exposure time. Use the change in the emitter efficiency of transistor (β_{DC}) due to change of the total irradiation dose as dosimeter for gamma radiation.

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