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THE EFFECT OF 8 MEV ELECTRONS ON 2 N2907A PNP TRANSISTOR

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Abstract: The PNP transistor 2N 2907A was irradiated with 8 MeV electron beam for different doses, to understand the displacement damage. It was observed that, the collector current and collector gain decrease for higher dose rates due to oxide trapping at Si-SiO_2 interface. The gain degradation was also studied for different doses of electrons and it was observed that gain of a transistor was reduced significantly. This degradation in the gain can be attributed to the fact that the increased base current due to the recombination centers introduced by the high energy electrons. The displacement damage factor was calculated using the gain. Similar study was carried out using Co-60 gamma source compared with 8 MeV and the details of these studies are presented in this paper.
Key words: Displacement damage, oxide trapping, degradation, recombination centers.

1. Introduction

Ever since the discovery of semiconductor devices, they have become integral part in the development of electronic components. Semiconductor electronic components are widely used in circuitry of gadgets, instruments etc. having innumerable applications. Thus application of semiconductor devices has reached enormous potential.

It is in this background the question arises sturdy/stable or effective are these semiconductor components when the standard parameters vary. It is to be precise, what happens to semiconductor electronic components when they are subjected to various radiations (e.g. x-rays, gamma rays, heavy ions, electrons etc). It becomes utmost important whether the given parameter remains unchanged or undergo changes when the electronic components under the influence of different types of radiations. The degradation due to radiation depends on various parameters like radiation dose, dose rate energy content, exposed time, type of component, radiation species etc. [1].

This brings us to the taste of assessing the damage caused by these radiations by analyzing the performance of the devices under strict conditions and careful monitoring during the process of radiation and after when we consider bipolar junction transistor (BJT), the gain (h_{FE}) and subsequently its collector characteristics effect becomes important after bombarding it with radiations. In fact in some cases to heavy dosage components can fail completely leading to breakdown of the instrument in use. The improvement of semiconductor components to withstand radiations without change in its characteristics thus becomes important. Electrons being the main component of study here it when excited by radiations shift the orbital electron to higher energy orbit or dislodge completely from the orbit. This leads to change in carrier concentration and shift in BJT characteristics.

2. Experimental Method

The PNP transistor 2N 2907A was irradiated with 8 MeV electron beam for different doses, to understand the displacement damage. It was observed that, the collector current and collector gain decrease for higher dose rates due to oxide trapping at Si-SiO_2 interface. The gain degradation was also studied for different doses of electrons and it was observed that gain of a transistor was reduced significantly. This degradation in the gain can be attributed to the fact that the increased base current due to the recombination centers introduced by the high energy electrons. The displacement damage factor was calculated using the gain. Similar study was carried out using Co-60 gamma source compared with 8 MeV and the details of these studies are presented in this paper. The various parameters of 2N 2907A, PNP transistor, were measured after exposing to 8 MeV radiation source at Microtron Centre, Mangalore University. The same parameters were also studied for the device after exposing to Co-60 gamma source at ISAC Bangalore using Semiconductor Parameter Analyzer-4145B [2].

3. Results and Discussion

The PNP transistor 2N2907A was characterized as a function of dose. The measurement of collector characteristics of the device at a constant current shows significant changes due to electron irradiation. A similar characteristic is observed for Co-60 also. In the characteristic curve the collector current in the saturation region decrease considerably as the accumulated dose increase, but collector emitter saturation voltage V_{CE} (sat) remains almost constant Fig. 1 shows the variation of forward current gain h_{FE}, estimated at a constant base current of 50μA as a function of accumulated dose. The current gain decreases considerably due to radiation. The most common effect of radiation a semiconductor devices is the gain degradation. This degradation in discrete BJTs can basically occur in two ways i.e. Bulk degradation and degradation by ionization. The bulk degradation occurs due to the atomic displacement in the bulk of the semiconductor when incoming energetic particle transfers momentum to atoms of the target silicon when transferred energy is sufficient the atoms of silicon can be ejected from its location leaving a vacancy or defect. The displacement damage is a bulk effect deep inside the semiconductor and produces an increase in the number of recombination centers. Recombination centers in the base region of the transistor reduce the minority carrier's life-time and so increases the base current and decrease the gain. In addition to recombination centers, displacement damage produces generation centers, trapping centers and scattering centers. Generation centers increases the reverse leakage current across the pn junction. This displacement damage is a bulk effect deep inside the semiconductor and produces an increase in the number of recombination centers. Recombination centres in the base region of the transistor reduces the minority carrier life-time and so increases the base current and decrease the gain. In addition to recombination centres, displacement damage produces generation centres, trapping centres and scattering centres. Generation centres increases the reverse leakage current across the pn junction. Trapping centres remove charge carriers. Scattering centres decrease the mobility of charge carriers. Both contribute to increase in resistance. Reverse breakdown voltage of the pn junction get increased slightly after irradiation.

There are several factors, which combine to determine transistor current gain (β), emitter efficiency, surface recombination velocity, recombination in either field, recombination in the base region and conductivity modulation [3]. Of these the recombination in the emitter field region and in the base region are two dominant factors, which influence the transistor current gain.

When BJTs are exposed to radiation, the current gain of the transistor decreases as the accumulated dose or fluence increases. The main cause for gain degradation is the displacement of atoms in the bulk of the semiconductor. This damage produces an increase in the number of recombination centers and therefore reduces minority carrier lifetime. Another cause for current gain degradation is the ionization in the oxide passivation layer, particularly that part of the oxide covering the emitter-base junction. The gain degradation can be represented by the equation

$$\Delta\left[\frac{1}{\beta}\right] = \frac{1}{\beta} - \frac{1}{\beta_o} \qquad -(1)$$

Where β_o and β are the gain values before and after irradiation.

Gain degradation is often analyzed by plotting the change in reciprocal gain $\Delta(1/\beta)$, versus radiation fluence. The term $\Delta(1/\beta)$ is known as the gain degradation figure. The effects of bulk and surface damage can be separated as follows

$$\Delta\left[\frac{1}{\beta}\right] = \Delta\left[\frac{1}{\beta}\right]_b + \Delta\left[\frac{1}{\beta}\right]_s \qquad -(2)$$

Where the suffixes, b and s refers to the bulk and surface contributions respectively. However, while the bulk contributions may be reasonably predicted from the analysis of minority carrier lifetime behavior, the surface contributions is highly dependent upon process factors. The reduction in h_{FE} with incident particle fluence is given by Messenger Spratt equation.

$$h_{FE} = h_{FEO} / (1 + h_{FEO} K\varphi) \qquad -(3)$$

Where h_{FEO} and h_{FE} are the gain values before and after irradiation φ is the fluence and K is the displacement damage constant. In order to calculate a displacement damage factor, it is necessary to convert from dose (rad(s)) to effective electron fluence. The rad equivalent 1 Mev electron fluence is about 4.08×10^7 p/cm^2 [4]. Fig. 2 shows variation of displacement damage K as a function of accumulated dose. The average value of K, calculated from the above equation agrees with the value reported in the literature for similar family of the device. The agreement between theoretical fit and experimental data is fairly good. Thus, the results observed indicate that the gain degradation in the investigated device is primarily due to displacement damage produced in the bulk of the semiconductor [5]. The displacement damage due to radiation also causes other important effects in bipolar transistors for e.g. the increase in collector-base leakage current (I_{CBO}), breakdown voltage. These parameters have been measured before and after irradiation. The I_{CBO} increases due to radiation. This increase in leakage current is due to the ionization in the surface oxide, particularly the region over the collector-base junction. At the same time the breakdown voltage of the transistors are exhibiting only a small increase due to radiation. This small increase in breakdown voltage is attributed to a decrease in the free charge carrier concentration. The increase in the I_{CBO} and breakdown has been observed on bipolar devices.

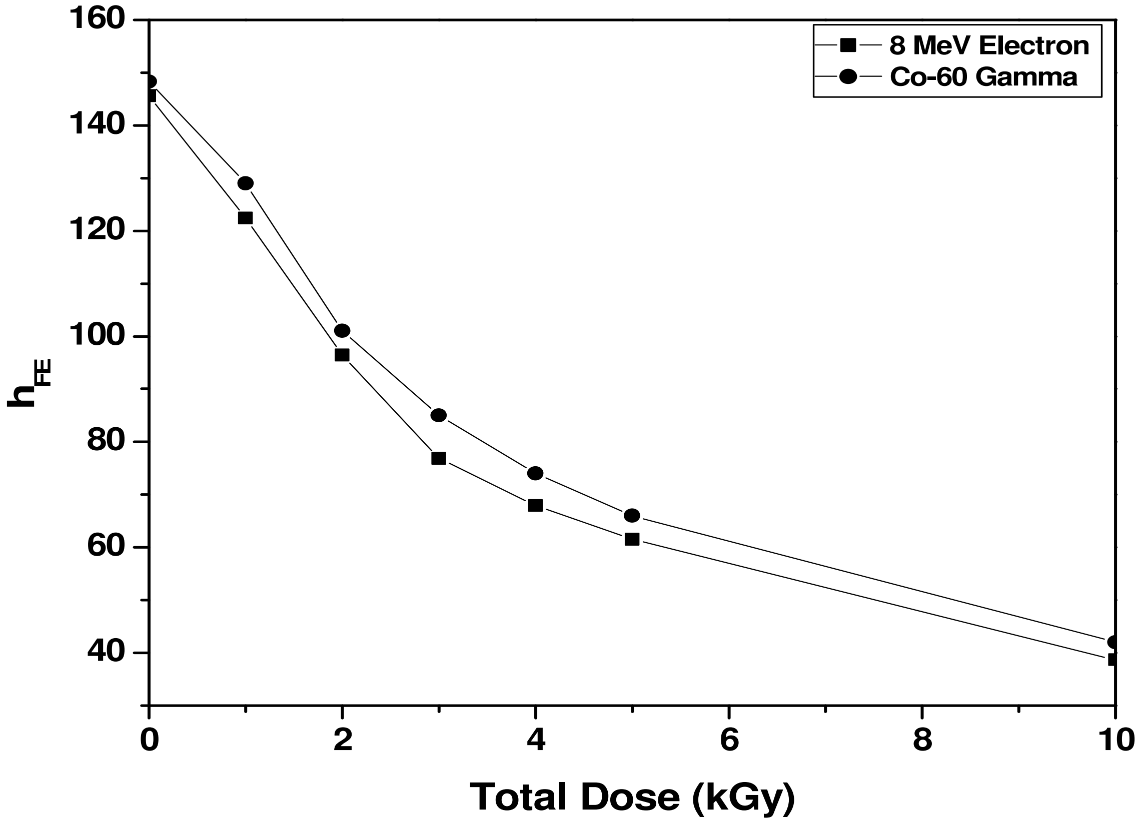

Fig. 1. h_{FE} as a function of total dose.

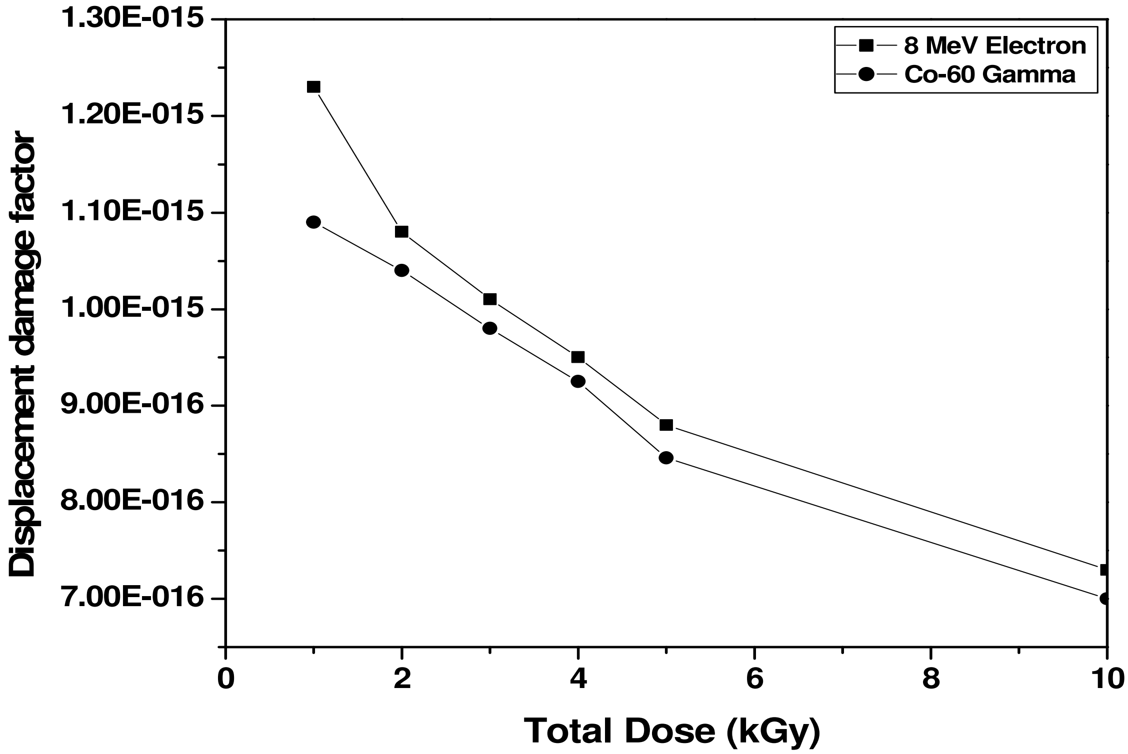

Fig 2. Displacement damage as a function of total dose.

4. Conclusion

The commercial bipolar transistor 2N2907A studied appears to be sensitive to radiation. The forward current gain of the transistor decreases more than 80% as the electron and gamma accumulated dose. The gain degradation observed in primarily due to displacement damage produced in the bulk of semiconductor and similar to that of the other transistor series.

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