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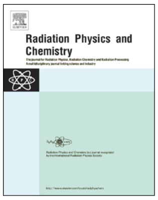

Investigation of irradiation effect on npn BJT electrical properties

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HIGHLIGHTS

- Results of irradiation effect on npn BJT transistor are reported.
- The radiations were a mixed neutrons-fission gamma rays and Co-60 gamma source.
- Main effect was the decreasing of the transistor current gain h_{FE}.
- The influence of h_{FE} decreasing on other transistor parameters was also analyzed.

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ABSTRACT

The irradiation effects of neutrons and gamma rays on a commercial type of npn Bipolar Junction Transistors (BJTs) are reported. The decrease of the current gain factor h_{FE} for increasing dose was analyzed. Reduction ratio for h_{FE} between 84% and 98% at the saturated reduction level have been obtained. This is due to a small decreasing in the collector current I_C and a large increasing in the base current I_B, where $h_{FE}=I_C/I_B$. Reduction ratio per dose indicates the higher influence of the neutrons than that of gamma for the same equivalent dose. Moreover, the voltage gain as a function of the frequency decremented after irradiation, and the collector saturated voltage (V_{CEsat}) was increased. These effects illustrate the damage in the function of BJTs.

1. Introduction

The performance of electronics devices in a radiation environment has a great important in evaluating their quality assurance. Nuclear radiation reaction with semiconductor devices depends on the energy and type of the radiation. Concerning the electronic components, the two main effects are ionization and atomic displacement. These two effects cause, in general, the creation of defects in Si/SiO_2 interface and Si bulk, respectively (Li et al., 2009; Schrimpf, 2004; Colder et al., 2001; Pien et al., 2010; Xing-Ji et al., 2010; Krishankumar et al., 2014).

The BJTs are used in various electronic systems such as spacecraft, defense equipments and high energy particle accelerators. Their main useful characteristics are high current drive, linearity, excellent matching, and appropriate gains in current, voltage and power (Schrimpf, 2004; Colder et al., 2001; Pien et al., 2010). The operation of BJT is based on the physical and electrical behavior of the minority and majority charge carriers during their transport into the three parts of the transistor: emitter, base and collector, which are separated by two junctions. Minority carriers are injected from the emitter through the base towards the collector to be collected finally as majority carriers.

The induced defects in BJTs by irradiation increase the electron-hole recombination rate, especially in the base. This leads to a reduction in the minority carriers life time, and to degrade mainly the values of I_B and h_{FE} (Li et al., 2009; Xing-Ji et al., 2010).

Within the frame of this work, experimental data describing the irradiation effects of a mixed neutrons-fission gamma rays (neutrons reactor) and Co-60 gamma source on BJTs were investigated. Moreover, the current gain degradation resulting from the change of the transistor currents was also an important objective of this work. Meanwhile, the radiation effect on the frequency response of voltage gain, V_{CEsat}, bias current, in addition to the effect of gamma dose rate, were studied.

2. Experimental

The investigated electronic devices are npn BJT 2N2222A discrete commercial transistors. The pre-rad value of h_{FE}, labeled h_{FE0}, is specified the transistor in hand and varies from one to other, even for the same company or batch. For the used transistors or

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the device under test (DUT) h_{FE0} varied from 150 to 280. Several sets, each consists of five DUTs having almost the same characteristics were irradiated by an accumulated gamma source dose/reactor irradiation time. The irradiation by gamma rays was performed by exposing the DUTs to Co-60 source for different doses measured by a chemical dosimeter; where the average radiation energy of Co-60 source is 1.25 MeV. While the irradiation by neutrons was achieved by location the DUTs inside one of the internal channel of Miniature Neutrons Source Reactor (MNSR) for different irradiation time. Therefore, they were exposed to a large spectrum of neutrons (from thermal to fast), in addition to associated gamma rays resulted from fission reaction. The maximum flux is related to thermal neutrons, which is $10^{12} n\ \text{cm}^{-2}\ \text{s}^{-1}$.

Results based on a previous modeling of the same transistors and MNSR have been used to calculate the equivalent absorbed dose during irradiation inside reactor (Assaf et al., 2014). According to this results, the dose in Gy is equaled to the irradiation time in seconds multiplied by a factor of 0.424 and 20.4 for neutrons and fission gamma, respectively. Therefore, the effect of irradiation inside reactor is expressed in this work either by irradiation time or by its equivalent dose.

In order to investigate the irradiation effect on DUT characteristics, two experimental set-up have been used. The first set up, was a Curve Tracer device, which provides the curves of $I_{CE}=I_C$ vs V_{CE} with the corresponding value of h_{FE} at a fixed set of I_B. The most measurements of h_{FE} by generated I_C -V_{CE} curves were achieved at fixed values of $I_B=50\ \mu\text{A}$ and $V_{CE}=2000\ \text{mV}$. The second set-up, was a typical common emitter circuit built around the DUT, it consists of Signal Generator, Digital Oscilloscope, DC Power Supply and Current Meter.

3. Results and discussion

The irradiation effect on the parameters of each DUTs set showed similar behavior with some deviation between them. The presented results for a specific parameter is resulted from the effect of an accumulated dose/irradiation time on only one the investigated DUT.

3.1. Radiation effect on h_{FE}

Fig. 1 presents an example of the variation of h_{FE} with dose after irradiation in the reactor and by Co-60 source. In this figure the dose related to the curve of "reactor" represents the equivalent dose corresponding to irradiation time from 0 to 150 s, while that of "Co-60 source" represents the measured dose from 0 up to 5000 Gy. It is useful to pointed out that the reactor equivalent dose has two contributions: the first is related to neutrons and the second is consequence of fission gamma. The maximum values of 63.6 Gy for neutrons and 3060 Gy for fission gamma, with a total of 3123.6 Gy were found out after irradiation by 150 s. The non-linear decreasing of h_{FE} related to the doses was observed on the two curves. Similar results were obtained by other types of radiation (Li et al., 2009; Schrimpf, 2004; Pien et al., 2010; Xing-Ji et al., 2010; Assaf et al., 2014; Johnston et al., 1994).

Analysis of the result shows the high effect of the first dose, meanwhile the decreasing was an almost saturated (saturated damage) at dose high levels of dose. Moreover, lower current gain was mainly attributed to the increasing of I_B (Schrimpf, 2004; Xing-Ji et al., 2010). In fact, I_B consists of tow main components. The first component I_{B1} is due to the hole injected from the base towards the emitter, which represents a diffusion current, and in most situations, it dominates. The second component I_{B2}, is due to the recombination of emitter's electrons with holes. These electrons diffuse through the base, and the recombination occurs either inside the emitter-base depletion or in the neutral base regions. As the defects, produced by the radiation, increase the recombination rate, I_{B2} is then increased with the increasing of radiation dose (Schrimpf, 2004; Assaf et al., 2014).

The measurement of h_{FE}. as function of I_B for different dose/irradiation time was also outlined as it is shown in Fig. 2. This test is an useful tool to predict whether a DUT was already irradiated or not, since the curves representing h_{FE} vs I_B is almost constant before irradiation, while they increase with I_B after irradiation.

The variation of h_{FE} factor was exploited above. The changing of this factor after irradiation for various DUTs is not comparable, by the fact of the variation of the initial value h_{FE0} even for identical transistors. This issue was taken into consideration through determining the damage effect by the following expression:

$$\Delta h_{FE}\% = \frac{\Delta h_{FE}}{h_{FE0}} \tag{1}$$

where $\Delta h_{FE} = (h_{FE0} - h_{FE})$ is the amount by which the current gain decreases from its pre-irradiation value. The quantities Δh_{FE} and $\Delta h_{FE}\%$ increase with the dose, and they express the current gain damage. Fig. 3 illustrates the variation of as a function of the dose corresponding to the results presented in Fig. 1. The maximum values of (saturated damage) were 84% and 98% for irradiation by 5 kGy of Co 60 source and during 150 s in the reactor, respectively.

3.2. Contribution of neutrons and fission gamma

Evaluation the effect of different radiation types having the

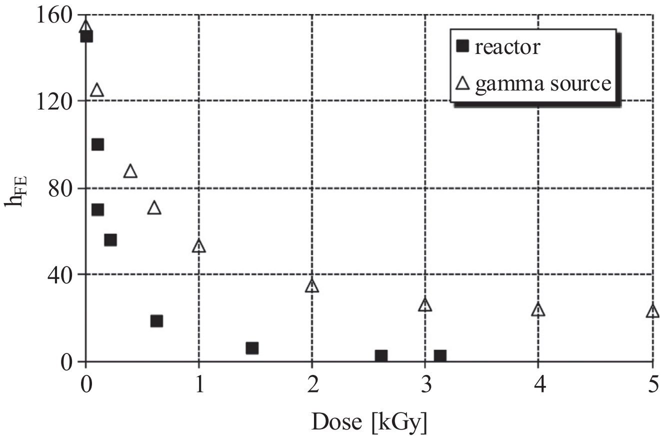

Fig. 1. Variation of the current gain h_{FE} as a function of the dose in cases of irradiation by gamma source and inside the reactor.

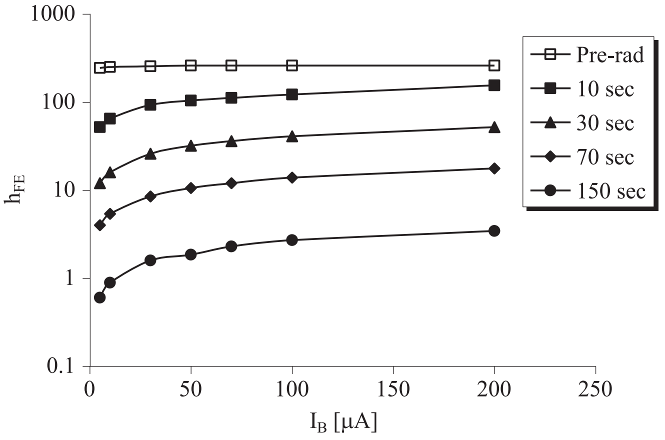

Fig. 2. Variation of h_{FE}. as a function of I_B for different irradiation time inside the reactor.