Physica B 404 (2009) 73–78

Contents lists available at ScienceDirect

Physica B

journal homepage: www.elsevier.com/locate/physb

High gamma dose induced damage on two types of discrete JFET transistors

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ARTICLE INFO

Article history:
Received 15 May 2008
Received in revised form
28 September 2008
Accepted 9 October 2008

Keywords:
JFET
Noise
Gamma
High dose

ABSTRACT

The effect of high Gamma ray dose on two types of commercial transistors having different DC specifications has been investigated. The transistors were discrete N-JFETs intended as front-end component in nuclear read-out systems. They were exposed to different Gamma doses with a maximum of 10,000 kGy. The irradiation influence was represented by the analysis of the DC and the induced noise characteristics.

The results show that the noise was more sensitive to irradiation than the DC parameters, and the radiation effect depends on the original DC specifications. It was also found that the first dose induces noise more than the next doses. Similar effects were observed either if the irradiation is done by one single dose or by many successive accumulated doses.

1. Introduction

Junction Field Effect Transistors (JFET) transistors are usually considered as radiation hardness; they are commonly used in radiation front-end circuits. Therefore, more works were carried out analyzing the effect of radiation considering JFETs structures and technologies, and also according to the type, dose and intensity of radiation [1–5]. It is well known that the most sensitive parts to the radiation in the electronics components are the semiconductors (usually Silicon, (Si) and its dioxide SiO_2). The deposition of Gamma radiation into such material causes, mostly, ionization, which is expressed by the generation of charged carriers (holes and electrons). In addition to ionization, there is a chance in producing an atomic-displacement effect indirectly by Compton electrons [6]. The generated carriers can recombine, separate, migrate or accumulate through the material. Some of them, especially the holes, can be trapped in certain locations in the JFET structure considered as point defects. The origin of these defects is either intrinsic or due to the radiation itself via atomic displacement effect. After the trapping of carriers, their detrapping also has a good chance of occurring, which gives rise to generation- recombination of these carriers. All of these processes depend on the type, structure and physical conditions of the JFET under irradiation. Their effects on the work of the JFET devices are expressed by changing some device characteristics such as variation in the electrical properties and increasing the electronic noise level [5,7,8]. Consequently, degradation on the function of the devices can take place and may be totally damaged.

In our previous work [4], only one type of discrete commercial JFET transistors (2N 4861) was irradiated by a maximum Gamma dose of 300 kGy. At this dose no changes were observed in the DC parameters. In this work, the effect of higher Gamma dose on the same type of these transistors and on other types (2N 5434) have been studied. The two types have different DC parameters, especially the transconductance g_m.

2. Noise measurements ' setup

Many works used noise as a good tool to evaluate the effect of nuclear irradiation on electronics devices [1–8]. The noise evaluation is usually expressed in terms of the Equivalent Noise of Charge (ENC) parameter.

As mentioned in Refs [4,9], the ENC was deduced from the noise and signal measurements using a typical nuclear data acquisition setup, which consists of a pulse generator (current detector simulated), charge-sensitive preamplifier (CPA), head amplifier (HA) and a multi-channel analyzer (MCA). The transistor or the device under test (DUT) was placed in the first (main) amplification stage in the CPA. The HA has a semi-Gaussian filter having 7 values of the shaping time τ. At HA output, the signal and the noise were measured using MCA, which acts as the pulse highest (amplitudes) analyzer. It provides information about the amplitude and the noise by the MCA channels number. The noise is described by the full-width at half-maximum (FWHM) of the Gaussian signal amplitude distribution, while the signal amplitude is the center of this distribution.

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doi:10.1016/j.physb.2008.10.015

The ENC is determined by ENC $= q(\mathrm{FWHM}/V_{HA})$, where q is the electron charge, and V_{HA} is the signal amplitude, after ENC represents the noise-to-signal ratio with the electrical charge dimension.

The systematic error of FWHM, which results from the noise background of HA and MCA, has been considered. Its value depends on τ, and it is varied from 2.3 to 3.5 channels on a total range of 8192 channels of MCA. The measurements random errors were also expressed by the standard deviations σ_{err} of five successive tests at the output of MCA. Both types of errors were considered and displayed in the figures representing the measurements results.

3. Noise characteristic of JFET

The total ENC resulted from noise sources of JFET transistors used in preamplifiers is generally given by the following equation [1,4,10]:

$$ENC = \left(ENC_1^2 + ENC_2^2 + ENC_3^2 + ENC_4^2\right)^{1/2} \tag{1}$$

where ENC_1, ENC_2, ENC_3 and ENC_4 correspond to four noise sources related to the JFET input. The first three terms represent voltages noise sources, while the fourth is a current source. The voltage and current noise sources are usually given by their power spectral densities (PSD) in V^2/Hz and A^2/Hz, respectively. The contribution of each ENC term depends on the JFET characteristics and on its physical conditions work. The most important term in our case is ENC_3, because it has an important contribution for the irradiated JFETs. Its noise is attributed to the Generation-Recombination centers activated by radiation ionization, which causes fluctuation on the drain-source current as a form of Lorentzian terms, and gives rise to G-R noise [1,2,4,7].

Experimentally and with such a setup, ENC is usually measured as a function of τ. In this regard, Eq. (1) can be rewritten in more details as follows [1,4]:

$$ENC(\tau) = \left[A_1 \frac{C_t^2}{g_m \tau} + A_2 \frac{a_f}{f} C_t^2 + A_3(k) \frac{a_{Li} C_t^2}{\tau} + A_4 q I_{gss} \tau\right]^{1/2} \tag{2}$$

where g_m is the transconductance of JFET; C_t is the sum of the total capacitance shunting the CPA input; a_f is a constant depending on the DC specifications of JFET; f is the frequency; a_{Li} is the maximum PSD of the G-R noise; I_{gss} is the gate leakage current in JFET; A_1, A_2 and A_4, are constants depend on the transfer function of the HA, A_3 is a coefficient constant depending on the transfer function of the HA, it varies also as a function of k where $k = \tau/\tau_{Li}$; and τ_{Li} is the constant time of the PSD related to G-R noise [1–4]. Note that the constants a_{Li} and τ_{Li} depend on the physical nature of the defect [1].

For a semi-Gaussian filter of 4th order, $A_3(k)$ equals to [1]

$$A_3(k) = 0.1024 \frac{35k^3 + 47k^2 + 25k + 5}{(1+k)^5} \tag{3}$$

In order to evaluate the contribution of each ENC component, the values of two parameters τ and C_t should be varied. In this setup procedure, τ takes seven values: 0.25, 0.5, 1, 2, 3, 6 and 10 μs. The contribution of each term of Eq. (1) is not measurable directly, but it is estimated from the total calculated ENC, i.e. the ENC(τ) curve.

At low and high values of τ, the dominated contributions of ENC are ENC_1 and ENC_4, respectively. The ENC_2 term is independent of τ and it has a constant value, which is usually small in the JFET devices [1], while ENC_3 depends on the function $F(\tau,\tau_{Li}) = \mathrm{A}_3(k)/\tau$ (see Eq. (3)).

4. Measurements before irradiation

4.1. DC characteristics of JFET

Measurements have been carried out on two types of commercial transistors. They are Silicon N channel JFET of the types 2N4861 and 2N5434, which are divided into two groups labeled J1 and J2, respectively. They have two different (I_{ds}–V_{ds}) characteristics as shown in Fig. 1, i.e. the drain-source current versus the drain-source voltage for several V_{gs}.

The values of g_m are deduced from the (I_{ds}–V_{ds}) characteristics, as the variations of the I_{ds}/V_{ds} ratio. They are the mean value calculated for 15 samples from each group. The result is listed in Table 1. More important data, taken from the specific transistors data sheet, is also shown in this table.

4.2. ENC measurements

The ENC test was carried out before irradiation. It has been performed on two samples of DUTs, i.e. one from each group.

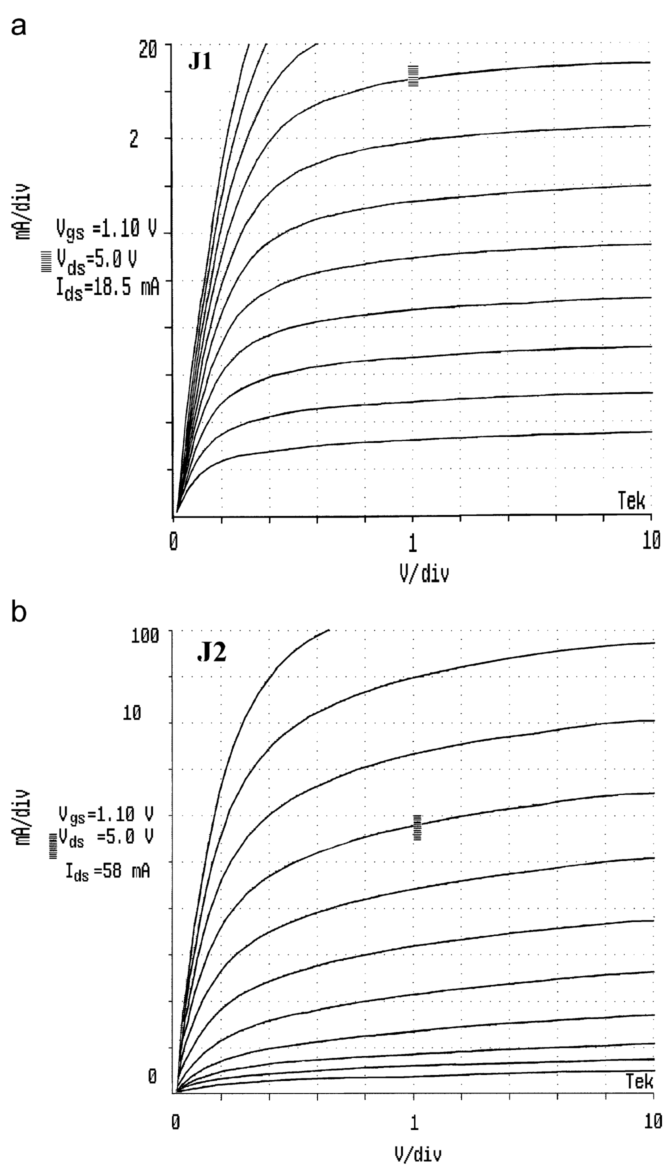

Fig. 1. The (I_{ds}–V_{ds}) characteristics of two samples from the two groups of J1 and J2 before irradiation.