THE USE OF LINEAR ELECTRON ACCELERATORS IN THE STUDY OF SEMICONDUCTOR AND OPTOELECTRONIC DEVICE BEHAVIOUR DUE TO IRRADIATION

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1 INTRODUCTION

As a result of the particle accelerator technique development, the basic researches as well as the applicative ones, related to the utilisation of radiation obtained with accelerators and radioisotopic sources in order to modify to the wish the properties of the matter, have received a greater attention.

The technological processes based on the ionising effect of the radiation, or radiotechnology as lately called, became competitive with the classical ones in many industrial applications. So, in the near future, it is possible that some radiotechnological methods, not having yet the equivalent among the classical ones, may substitute the latter as soon as they become more profitable or reveal more performant parameters in point of industrial reliability. Of course, some of them will continue to exist in parallel. So, as an example, we may consider some permanent changes after electron or fast neutron irradiation, such as carriers storage time in a **pn** junction or transistor current gain that could be used as radiotechnological stages in semiconductor electron device production.

2 ELECTRON RADIATION EFFECTS ON SOME PARAMETERS OF SEMICONDUCTOR DEVICES

We propose a simple method to measure the variation of some important parameters for a set of **n-p-n** type bipolar transistors, τ_{BF} and τ_F when irradiated with fast electrons. The two time constants are dependent on the technological parameters of the transistors, τ_{BF} stands for the lifetime of the minority carriers within the base and τ_F represents the transient time of the carriers through the transistor base.

Suppose the transistor operates within the active region. The positive input pulse, supplied by a rectangular pulse generator, is applied to the base of the transistor via a resistance, R connected in parallel to a capacitor, C. Under these circumstances the minority carriers in excess are injected into the transistor base.

The total charge is as per the below relations:

$$q_F(t) = q_{FR}(t)+q_{FC}(t) = V_B\tau_{BF}/R\cdot(1-e^{-t/\tau_{BF}}+RC/\tau_{BF}\cdot e^{-t/\tau_{BF}}) \quad (1)$$

where

$$q_{FR}(t) = V_B\tau_{BF}/R\cdot(1-e^{-t/\tau_{BF}}) \quad (2)$$

$$q_{FC}(t) = CV_B\, e^{-t/\tau_{BF}} \quad (3)$$

I.e. the charge of the in-excess carriers that enter into the base via the resistance R, the charge supplied by the capacitor C, including V_B, which is the amplitude of the pulse applied to the emitter-base junction. Equations (1) and (3) evidence that for $t = 0$ the total charge in excess is the capacitor charge:

$$q_F = CV_B \quad (4)$$

$$RC = \tau_{BF} \quad (5)$$

Since $\tau_{BF} \sim 1\cdot10^{-7}$ s, from relation (2) one can see that for a time of several tenths of μs, $q_{FR}(t)$ is increasing fast up to a saturation value while $q_{FC}(t)$ is tending towards zero. From relation (1) one can also observe that, when the charge in the base is almost instantaneously reaching a constant value, the collector current is given by the relation:

$$i_C = q_F/\tau_F \quad (6)$$

For the measurement of parameters τ_{BF} and τ_F, a circuit in which the transistor is used as a voltage controlled amplifier was employed [1].

2.1 Determination of Parameters τ_{BF} and τ_F

The lifetime value of the minority carriers can be obtained with equation (5) and the collector current value may also be obtained with the equation:

$$i_C = V_C/R_C \quad (7)$$

When combining the equation (4), (6) and (7) for the transition time, the following equation can be obtained:

$$\tau_F = CR_CV_B/V_C \quad (8)$$

The values of R, V_B and V_C can be directly read while C and R_C are constants of the equipment. Once τ_{BF} and τ_F are determined, it is possible to calculate some other parameters of interest for the characterisation of the transistors. Thus, the static current gain (common emitter configuration) is given by the ratio:

$$\beta_F = \tau_{BF}/\tau_F \quad (9)$$

The cut-off frequency:

$$f_T = 1/\tau_F \quad (10)$$

and the transport factor:

$$\alpha_T = 1-\tau_F/\tau_{BF} \quad (11)$$

Table 1:
Variation of interesting parameters versus incident electron fluence for **n-p-n** transistors type

Crt. no.	Φ (cm^{-2})	V_B (V)	R (Ω)	V_C (V)	τ_{BF} (s)	$1/\tau_{BF}$ (s^{-1})	τ_F (s)	$f_T=1/\tau_F$ (s^{-1})	β_F	$1/\beta_F$	α_T
1	0	1.5	442	8	$2.2\ 10^{-7}$	$4.5\ 10^{6}$	$2.8\ 10^{-9}$	$3.6\ 10^{8}$	79.0	0.013	0.987
2	$3\ 10^{14}$	1.6	260	7.4	$1.3\ 10^{-7}$	$7.7\ 10^{6}$	$3.2\ 10^{-9}$	$3.1\ 10^{8}$	40.0	0.025	0.975
3	$9\ 10^{14}$	1.6	220	7.2	$1.1\ 10^{-7}$	$9.1\ 10^{6}$	$3.3\ 10^{-9}$	$3.0\ 10^{8}$	33.0	0.030	0.970
4	$1.8\ 10^{15}$	1.5	160	6.6	$8.0\ 10^{-8}$	$1.3\ 10^{7}$	$3.4\ 10^{-9}$	$2.9\ 10^{8}$	26.0	0.038	0.962
5	$3.6\ 10^{15}$	1.5	108	6.4	$5.4\ 10^{-8}$	$1.9\ 10^{7}$	$3.5\ 10^{-9}$	$2.9\ 10^{8}$	15.0	0.067	0.933
6	$7.2\ 10^{15}$	1.4	66	5.0	$3.3\ 10^{-8}$	$3.0\ 10^{7}$	$4.2\ 10^{-9}$	$2.4\ 10^{8}$	8.0	0.125	0.875
7	$1.44\ 10^{16}$	1.5	36	4.2	$1.8\ 10^{-8}$	$5.6\ 10^{7}$	$5.4\ 10^{-9}$	$1.9\ 10^{8}$	3.4	0.249	0.706
8	$2.88\ 10^{16}$	1.5	32	3.8	$1.6\ 10^{-8}$	$6.3\ 10^{7}$	$5.9\ 10^{-9}$	$1.7\ 10^{8}$	2.7	0.370	0.630

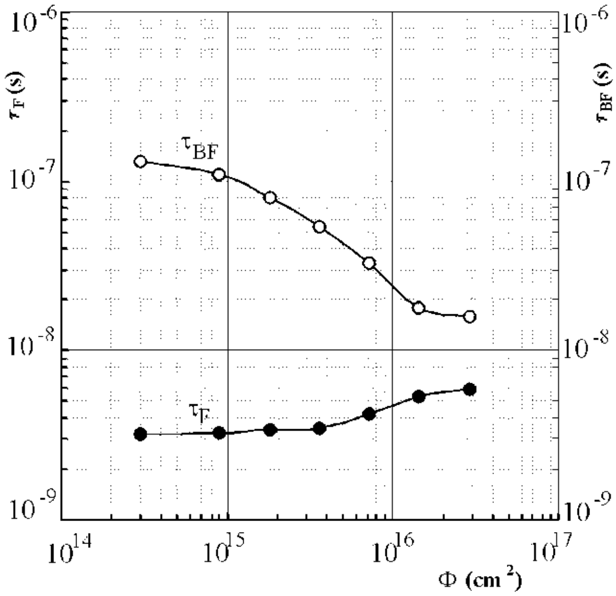

Fig. 1: τ_F and τ_{BF} parameter variation versus electron fluence

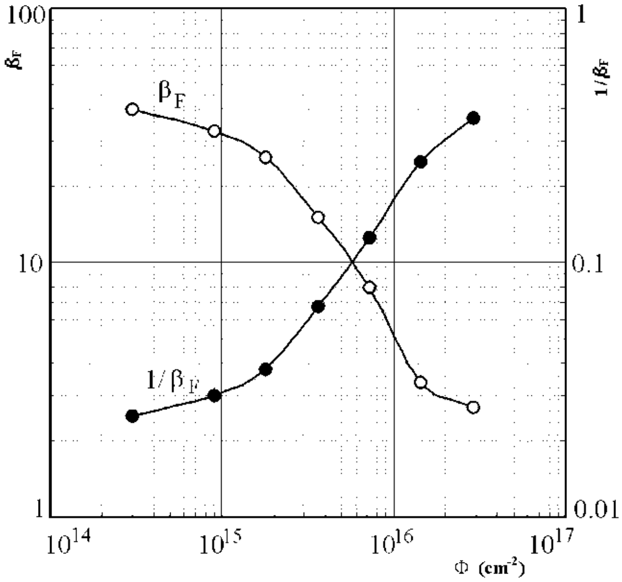

Fig. 2: β_F and $1/\beta_F$ parameter variation versus electron fluence

2.2 Experimental Results and Discussion

Irradiation was performed with a linear electron accelerator, at an average of 7MeV and an electron flux $\varphi=5\cdot10^{11}$ $cm^{-2}s^{-1}$, with the electron fluence ranging $\Phi_e=(3\cdot10^{14}\div3\cdot10^{18})$ cm^{-2}. When calculating the fluence, the cumulated irradiation time was considered. After each irradiation, the parameters V_R, R, V_C were measured and then the times τ_{BF} and τ_F. The variation of the parameters versus the electron fluence for bipolar low power silicon **n-p-n** transistors is presented in Table 1.

Let us focus on the directly measured parameters.

Fig. 1 shows the variation of τ_F and τ_{BF} with Φ. On the graph, for small fluences, there is an unimportant decrease of τ_{BF} up to $\Phi \cong 1\cdot10^{15}$ cm^{-2}, the decrease starts to slows down and, for large fluence, a more evident decrease is occurring.

An interesting behaviour may also be noticed for the type of minority carrier transit τ_F through the base whose value is about constant up to $\Phi \approx 6\cdot10^{15}$ cm^{-2}, wherefrom it starts to increase.

An important parameter is the static current gain β_F defined by relation (9). Its variations with the incident electron fluence are shown in Fig. 2. According to the definition, the variation of β_F should be alike the variation of τ_{BF}, which can be seen on figure 1 and 2.

Figure 2 illustrates the variation of parameters β_F and $1/\beta_F$ with electron fluence. Generally, Lofferski law should be followed, i.e.: $1/\beta_F = 1/(\beta_F)_0 + K\Phi$
where $(\beta_F)_0$ is the static current gain before irradiation and Φ is the electron fluence.

For small fluences, some deviations from Lofferski low can be noticed, but for larger fluences, the law is followed and the constant K (also called the transistor degradation constant) can be determined by graph.

For high fluence where τ_F is increasing, degradation of the static current gain β_F is more obvious (Fig. 3).

The switching parameter in the saturation regime, base charge storage time t_S and fall time t_F were the most sensitive to the irradiation effects. At high fluence they decreased proportionally with the electron fluence, beginning with $1\cdot10^{15}$ $e^{-}\cdot cm^{-2}$ [2].

The fall time t_F varies quantitatively differently as compared with the storage time t_S (Fig. 4).

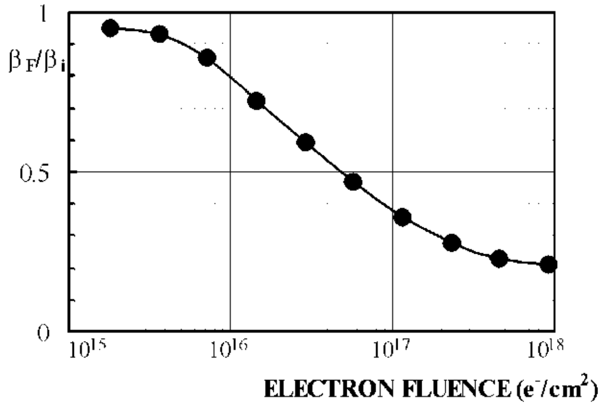

Fig. 3: The effect of electron fluence on the normalized static current gain (β_F)

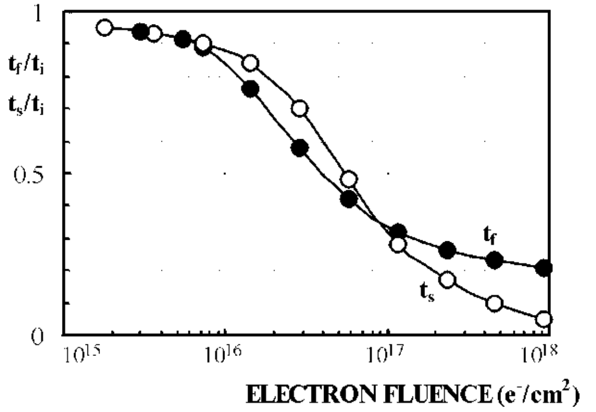

Fig. 4: The effect of electron exposure on the normalized storage time (t_S) and fall time (t_F)

By electron irradiation, in boron doped silicon in the semiconductor forbidden band, deep donor levels are induced. In this way, the number of recombination centres in neutral base is increasing while minority carrier lifetime τ_{BF} is decreasing as per the law: $\tau_{BF} \sim 1/C_nN_t$

where $N_t = \eta\Phi$ represents the concentration of the radiation effects.

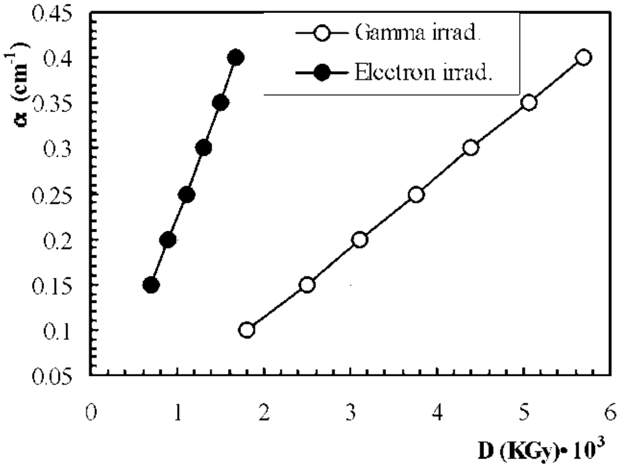

Fig. 5: Variation of the absorption coefficient α versus the irradiation dose gamma and electron respectively

2.3 The Radiation Defects Formation in Laser Active media

The possibility to obtain the colour centres in lithium fluoride crystals as a result of electrons and gamma rays irradiation gave the opportunity to use these irradiation for Q-switches for the Nd: YAG lasers working in the pulse regime and as active media for the lasers tuned in the near infrared region. Q-switches for resonators of the Nd: YAG lasers are based on the saturation non-linear optical effect of the absorption in crystals of $LiF:F_2^-$ type. The $LiF:F_2^-$ crystals can be obtained by electron gamma and neutron irradiation.

When irradiated by gamma radiation, one may observe much lower irradiation efficiency. The efficiency of electron irradiation is much better, the irradiation time being only 3-4 hours as compared to 300 hours necessary for the irradiation in the gamma radiation field [3].

Fig. 5 illustrates the variation of the absorption coefficient α for $LiF:F_2^-$ crystals at 1.064 μm wavelength versus the irradiation dose gamma and electron respectively.

Electron irradiation was carried out by a linear electron accelerator that generates irradiation dose rates up to $5 \cdot 10^5$ Gy/h at 7 MeV electron average energies.

3 CONCLUSION

The method offers the possibility to directly measure the parameters τ_{BF} and τ_B and next, to determine other important parameters, such as: β_F, f_T, α_T, i.e. an attempt to find a relation between the intrinsic parameter and the electrical one.

For large fluences where the bulk recombination effects are dominant, Lofferski law is met and the degradation constant K, can be determined. Knowing the value of the constant K, it is possible to get information on radiation defect, level induced by irradiation and generally on the behaviour in the radiation fields. The LiF: F_2^- crystals can be obtained from LiF crystals irradiated with a very good efficiency in an electron beam.

REFERENCES

[1] A. S. Grove, Physics and Technology of Semiconductor Devices, New York, John Wiley and Sons, Inc, 1967.
[2] N. Baltateanu, Doctoral thesis, 1979.
[3] M. Jurba, N. Baltateanu, I. Spanulescu, S. I. Spanulescu, Anca Gheorghiu, Eur. Phys. J. AP 2, 253-256, 1998.