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The Results of Simulation of the process of occurrence of damages to the Semiconductor Elements of Radio-Electronic Equipment under the influence of Multi-Frequency Signals of Short Duration

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ABSTRACT

In articles questions of occurrence of damages in semiconductor elements at influences on them of multi-frequency space-time signals (MF STS) are considered. The studies to improve the affection accumulation method for the case of influence to the semiconductor element base by the multi-frequency space-time signals have been conducted. The estimates of the probability of affection of the semiconductor element under the influence of the multi-frequency space-time signals have been obtained. As a result of the researches conducted, the method of affection accumulation for the case of the influence of MF STS on the semiconductor element base has been improved. This method involves the usage of statistical characteristics of thermal energy to estimate the probability of degradation of the p-n junctions for normal (diodes, transistors) and equable (integrated circuits) distribution laws. The results of modelling the calculation of the probability of damage to semiconductor elements of electronic equipment under the influence of multi-frequency signals of short duration are presented.

Key words: semiconductor, affection, probability, microprocessor technology, control system, space-time signal, mathematical model.

1. INTRODUCTION

The use of new physical principles and technical solutions when creating perspective generating means, the improvement of theoretical methods of affection of the semiconductor elements necessitate the explanation of the effects of irreversible affection when using a sequence of short signals. The purpose of the work is to develop a method of affection accumulation, which implies that under the influence of a single impulse there is a slight local change in the structure, for example, the formation of a defect. The failure of a device will occur when a certain critical number of defects is reached [1-14].

Based on the Arrhenius activation theory, it is advisable to conduct a number of calculations of the affection of the semiconductor elements and obtain the probabilistic affection estimates using the normal and equable distribution laws for the thermal theory that excites the p-n junction, including also taking into account the number of impulses, duty cycle and the power of the generated signal [15].

The aim of the article is to model the calculation of the probability of damage to the semiconductor elements of radio-electronic equipment under the influence of multi-frequency signals of short duration.

2. MAIN MATERIAL

2.1The results of calculating the probability of damage to the semiconductor elements of electronic equipment under the influence of multi-frequency signals of short duration

The E_o value can be estimated as k_bT_{cr}, where $T_{cr}=(T_0+\Delta T_{cr})$ is the critical temperature value used in the Wunsch-Bell model, upon reaching which the p-n junction is damaged. The ΔT_{cr} value for different p-n junctions, for example, the silicon ones, can be determined from the empirical expression provided in the work. So for p-n junctions with avalanche breakdown voltage -7…-9 V, ΔT_{cr} = 350…500°.

Figure 1 shows the dependence of occurrence of damages to the semiconductor elements for the normal distribution law P on the number of acting radio impulses N. The graphs are created with the following parameter values: $E_{av}/k_b T(\tau_{sts}) = 10$; $\delta=3$, $\gamma=10^{-4}$. Graph 1 corresponds to $T_{sts}=250$ ns, $\Delta/E_{av}=1,3$, $E_0/E_{av}=1$, Q=50; graph 2 – $T_{sts}=250$ ns, $\Delta/E_{av}=1,3$, $E_0/E_{av}=0,5$, Q=25; graph 3 – $T_{sts}=250$ ns, $\Delta/E_{av}=1,8$, $E_0/E_{av}=0,3$, Q=16; graph 4 – $T_{sts}=250$ ns, $\Delta/E_{av}=2$, $E_0/E_{av}=0,25$, Q=8.

Figure 2 shows the obtained similar dependence of the probability of occurrence of damage P with a uniform distribution law on the number of acting radio impulses N for $\delta=3$; $\gamma=10^{-4}$. Graph 1 corresponds to $\Delta Э/Э_o=1$, $T_{пsts}=250$ ns; $\tau_{sts}=5$ ns; $E_0/k_b T(\tau_{sts})=10$; graph 2 – $\Delta E/E_o=0,5$, $T_{sts}=250$ ns; $\tau_{sts}=10$ ns; $E_0/k_b T(\tau_{sts})=10$; graph 3 – $\Delta E/E_o=0,3$, $T_{sts}=250$ ns; $\tau_{sts}=10$ ns; $E_0/k_b T(\tau_{sts})=5$; $\Delta E/E_o=0,25$, graph 4 – $T_{sts}=250$ ns; $\tau_{sts}=10$ ns; $E_0/k_b T(\tau_{sts})=5$.

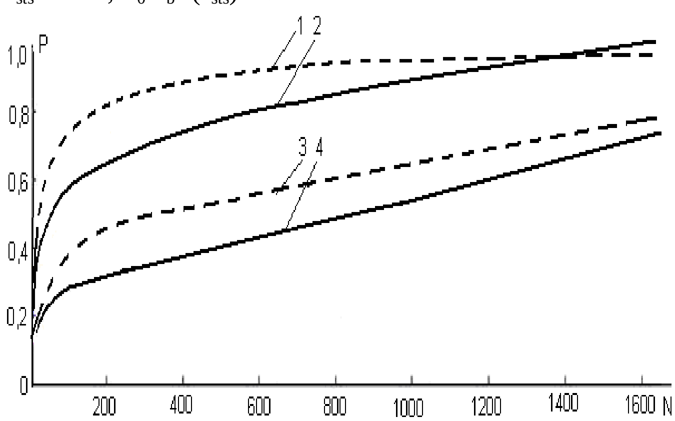

Figure 1: The dependence of the probability of occurrence of damages of the p-n junction on the number of impulses in a burst N for the normal distribution law

The $E_0/k_b T(\tau_{sts})$ parameter is inversely proportional to the maximum temperature that is reached in the p-n junction and shows how many times the signal energy is less than the thermal energy sufficient for the occurrence of damages to the element. The $\Delta E/E_o$ parameter characterizes the energy spread of the signal at different defects of the p-n junction, and in the general case, it can be about 1.

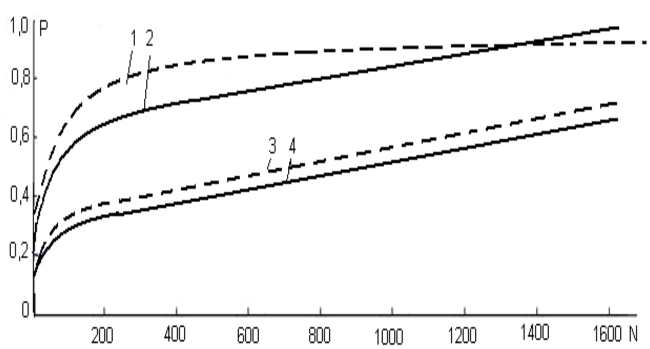

Figure 2: The dependence of the probability of occurrence of damages to the p-n junction on the number of impulses in a burst N for a uniform distribution law

The analysis of Figure 1, 2 shows that with an increase in the number of impulses, the probability of occurrence of damages to the p-n junction tends to its limiting value. At a one-stage distribution of frequencies for the follow-up period of the signals in the burst, the relaxation time is shorter, the occurrence of damages to the elements can already occur at 800 … 1000 impulses in the burst. In the case of a multi-stage frequency distribution, the energy of a single signal is shorter, and the degradation occurs at N=1600 … 2000 impulses at the signal energy values determined above. In this case, the dependence of occurrence of damages on the impulse duration is much less significant.

Figure 3 shows the dependence of occurrence of damages to the semiconductor elements P on the impulse repetition period T_{sts} for the normal distribution law. The graphs are created at $E_{av}/k_b T(\tau_{sts})=10$, $E_{cr}/E_0=10$, $\delta=3$, $\gamma=10^{-4}$, N = 1000. Curve 1 corresponds to $\Delta/E_{cr}=10$, Q=50; curve 2 – $\Delta/E_{cr}=7$, Q=25; curve 3 – $\Delta/E_{cr}=4$, Q=16.

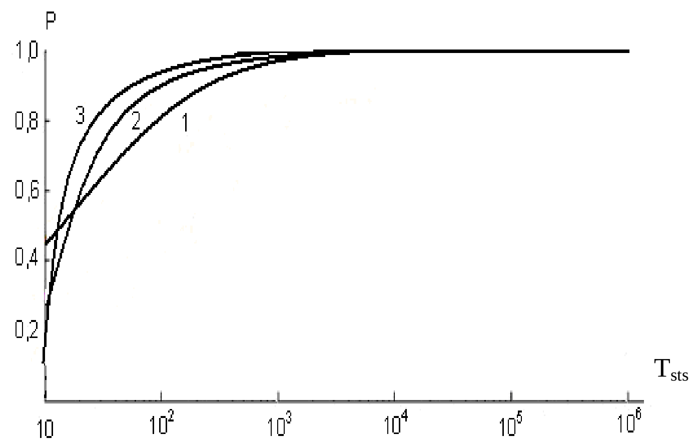

Figure 3: The dependence of the probability of occurrence of damages on the impulse repetition period

$$p_N = V_0 \tau_{пвс} \exp\left[-\frac{E_a}{k_b T(\tau_{sts})}\right] \eta\left(N, T_{sts,\gamma}\right) \qquad (1)$$

where $\eta\left(N, T_{sts}, \gamma\right) = \dfrac{1-\exp\left(-\gamma N T_{sts}\right)}{\exp\left(-\gamma T_{sts}\right)} \exp\left(-\gamma T_{sts} + \gamma \tau_{sts}\right)$

E_a – the MF STS sequence energy;
V_0 – the constant depending on the defect type;
K_b – the Boltzmann constant;
T – the rectifier contact temperature which changes under the action of the MF STS sequence;
γ– the relaxation parameter describing the process of restoration of a semiconductor structure;
T_{sts} – the follow-up period of MF STS;
T_{sts}– the duration of a single MF STS;
N– the number of MF STS in a burst.

It follows from the expression (1) that at γT_{sts}, $N\gamma T_{sts} \ll 1$ log(N) is proportional to the probability of occurrence of damages and it increases with the increment in the number of acting pulses, and for $N\gamma T_{sts} \gg 1$ the probability P tends to a constant value.

Figure 4 shows the dependence of the probability of occurrence of damages to the semiconductor elements on the relative energy E/E_{cr} for the normal distribution law. Graphs in fig. 4 are created at $\Delta/E_{av}=1$, $E_{av}/E_0=1$, $\delta=1$, N=800: curve 1 – $\gamma T_{sts}=10^{-2}$; curve 2 – $\gamma T_{sts}=10^{-5}$.

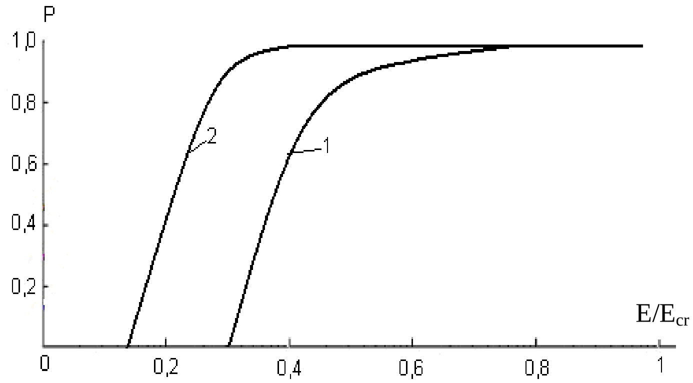

Figure : The dependence of the probability of occurrence of damages to semiconductor elements of the radio-electronic equipment on the relative energy

Curves in Figure 4 shows that the failure of a semiconductor device occurs when a certain power level is exceeded.

If we fix the probability of occurrence of damages to the semiconductor elements of the radio-electronic equipment at the level of 0.5, we can determine the dependence of the relative energy E/E_{cr} of the impulse on the impulse repetition period T_{sts} in the burst. Assuming $E_o=k_bT_{cr}$, for the case $N\gamma T_{sts}<<1$ we will receive:

$$\frac{E_{50\%}}{E_{cr}} \sim \frac{1+\frac{\Delta}{2k_b T_{cr}}}{\delta+\ln\left(tT_{sts}\right)}.$$

From the expression obtained, it follows that with a decrease in the impulse repetition period, the energy $E_{50\%}$ of the impulse necessary for the occurrence of damages to the semiconductor elements of the radio-electronic equipment decreases.

Thus, an improved method for calculating the probability of occurrence, in which the statistical features of the damage process are determined by energy fluctuations, has been suggested. The method allows to describe the dependence of the probability of occurrence of damages on the number of acting radio impulses N, the burst period T_{sts}, the impulse duration τ_{sts}, duty cycle and signal strength.

Summarizing the obtained results, it is possible to make the following conclusions which are important for the practical application of this methodology: in order to increase the probability of occurrence of damages to the semiconductor elements of the radio-electronic equipment when using the MF STS sequence, it is advisable to use the ability to control the multi-stage frequency distribution over the aperture of the phased antenna system, which will allow to “fill in” the diagram of the antenna system direction with a set of useful focused signals, each of which leads to a local p-n junction defect, for a range of up to 5 km. The smaller is the duty cycle, the greater the number of signals will be: at Q = 25, about 800 impulses are sufficient, at the same time, the probability of occurrence of damages to the semiconductor elements of the radio-electronic equipment will increase by almost 8% in relation to the same number of impulses for a one-stage distribution, at Q = 16, the probability of occurrence of damages to the semiconductor elements of the radio-electronic equipment will increase by 12% (Figure 1, 2).

With a decrease in the impulse repetition period, the probability of occurrence of damages to the semiconductor elements of the radio-electronic equipment increases as well.

From the multistage distributions with different duty cycle considered in the research, it follows that the impulse repetition frequency decreases with the decrease in the duty cycle: at = 50 the degradation occurs at T_{sts} = 250 ns, at Q = 25 at T_{sts} = 180 ns, at Q = 75 at T_{sts} = 800 ns (fig. 3).

With the accumulation of energy by a semiconductor element, the probability of its degradation increases. What is more, in the damage accumulation mode (curve 2, fig. 4), it is the absolute energy that is important, and not its increment, as it is in the thermal breakdown mode (curve 1, fig. 4). So with the same relative energy in both modes at the level of 0,4, the probability of occurrence of damages to the semiconductor elements of the radio-electronic equipment in the damage accumulation mode is by 0,2 higher than in the thermal mode.

3. CONCLUSION

The mathematical modelling has been carried out and the estimates of the probability of occurrence of damages to the semiconductor elements of the radio-electronic equipment using the sequence of powerful multi-frequency space-time signals with different numbers of exciting impulses N, the burst period T_{sts}, the impulse duration τ_{sts} and the signal power have been obtained. When using the multi-stage frequency distributions, the probability of occurrence of damages to the semiconductor elements of the radio-electronic equipment increases by 12 … 20%.

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