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The Increase of the Lifetime of the Onboard Electronics of Spacecrafts By High-temperature Annealing of Radiation Defects

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Abstract

The technique for increasing the maximum lifetime of the electronic equipment for space applications was developed. The technique is based on controlled temperature annealing of radiation defects accumulated in integrated microcircuits under the impact of ionizing radiations of space environment.

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1. Introduction

Electronic technical products are exposed to ionizing radiation in the process of operation in outer space conditions. Radiation effect leads to a degradation of the amplification factor of a bipolar transistor, as well as to a shift in the threshold voltages of MOS structures [1]. As a results, there are functional and parametric failures of the onboard electronics of a spacecrafts.

The repair of electronic equipment in space conditions by replacing the failed modules is either extremely difficult or impossible, since the necessary components must be delivered from the Earth and installed in the place of the failed products.

It is known that an increase in the temperature of crystals of integrated microcircuits leads to partial or complete annealing of radiation defects accumulated in the process of operation under radiation exposure. Periodic annealing of integrated microcircuits directly onboard space vehicles can serve as a good tool to increase the radiation resistance of modules of radio electronic equipment for space applications.

2. Materials and Methods

The main element of modern bipolar semiconductor electronics is a vertical bipolar transistor. For experimental studies of the influence of post-radiation annealing on the rate of further radiation degradation of bipolar devices, the bipolar transistor 2N2222A, which was the most widely used in modern electronic devices and devices, was chosen.

The irradiation of the device was performed on an X-ray source for an absorbed dose of 15 krad (Si). After irradiation, the device was annealed at three different temperatures: 85°C, 125°C и 165°C. During the annealing, the volt-ampere characteristics of the Hummel transistor were measured, measurements were made at a temperature (25 ± 0.1)°C. After a series of experiments on annealing, the irradiation of the transistor was continued under the same conditions as before annealing.

The transients of 2N2222A base current at 0.55V bias of emitter-base junction is presented in Figure 1 for all the experiment steps.

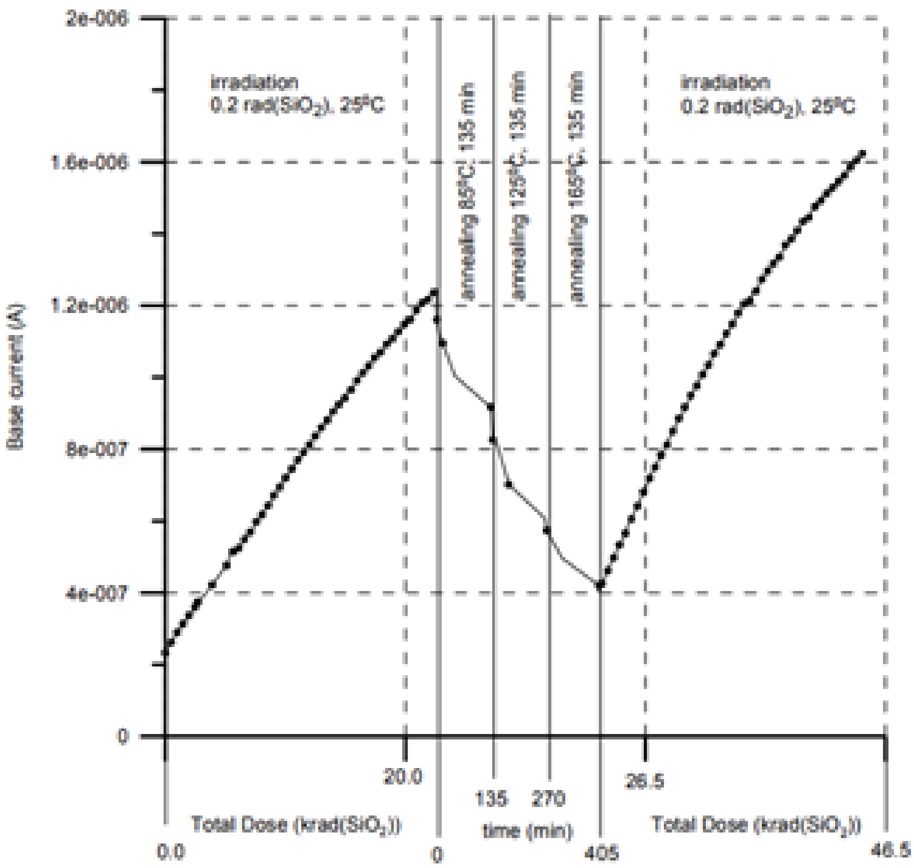

Figure 1: Dependence of the base current on total dose and annealing time at emitter-base voltage for 2N2222A.

For the practical application of the technique for annealing radiation defects accumulated in integrated microcircuits during operation in space conditions, it is necessary to be able to control the heating of microcircuits directly on board the spacecraft. Heating can be achieved by supplying a lower reverse polarity supply voltage, since modern chips are manufactured according to planar technology and contain a p–n junction between the pocket and the substrate, which is closed in the normal operating mode of the microcircuit and opens when the polarity of the supply voltage is changed. As a result, with a reverse power supply, the integrated circuits are diodes that are heated by an electric current passing through them. The temperature of the crystal is calculated from the temperature sensor on the spacecraft, the power consumed by the microcircuit in the annealing mode, and the crystal-plate thermal resistance determined experimentally in the laboratory before launching the space mission. According to the experimentally obtained temperature dependence of the annealing time constant of radiation defects, considering the actual temperature of the crystal of the microcircuit, the optimum time necessary for annealing is determined. Annealing starts at the command of the operator transmitted from the Earth, and ends after the estimated time by the command to return to normal operation mode.

3. Conclusion

In the course of the experiments, it was established that post-radiation annealing leads to a partial (more than 50%) restoration of the parameters of bipolar devices. The rate of annealing of radiation defects sharply increases with increasing temperature. The optimal annealing temperature can be considered 165°C, since a further increase in the temperature can lead to spontaneous dismantling of microcircuits from the surfaces of printed circuit boards due to melting of the assembly solder. At the second stage of irradiation, it is established that the rate of radiative degradation of bipolar devices increases after annealing. A numerical analysis of the obtained results allows us to conclude that the use of several annealing cycles during operation is capable of increasing the failure rate of bipolar electronic products by 2–4 times.

References

[1] Pershenkov, V. S., Popov, V. D., and Shalnov, A. V. (1988). Surface radiation effects in elements of integrated microcircuits. M: Energoatomizdat.