

Influence of preliminary irradiation by gamma-quanta on development of catastrophic failures during operation of IR-LEDs

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Abstract. We have considered the influence of preliminary irradiation by ^{60}Co gamma quanta on development of catastrophic failure during long-term operation of IR-LEDs based upon dual AlGaAs heterostructures. Irradiation was realized in passive power mode of the LEDs prior to aging. Two specific doses of irradiation were used. The first irradiation dose corresponded to the first stage of emission power drop of the LEDs irradiated by gamma-quanta, which is attributed to the radiation-stimulated reconstruction of the initial defect structure of the LED crystal. The second dose corresponded to the second stage of emission power drop, which is attributed solely to the introduction of radiation defects. Aging under long operating time conditions was simulated by a step-stress approach. We have established that the preliminary irradiation by gamma-quanta can be used in manufacturing technology of LEDs to improve their operating parameters on condition that irradiation doses are chosen in strictly provide area of the radiation-stimulated reconstruction of the initial defect structure.

1. Introduction

Nowadays infrared wavelength range light-emitting diodes (IR-LEDs) operate under the conditions of various types of ionizing radiation. It leads to combined influence of ionizing radiation and long-term operation factors. Whereas this influence limits operational reliability of LEDs. In this case, we interpret that the combined influence is the impact of two or more factors spread out over a period of time. It should be noted that today there is insignificant number of works about combined irradiation of semiconductor devices [1-4], while the information about combined influence of long-term operation and ionizing radiation is practically lacking.

In the preliminary investigation we have established that the reliability of the LEDs and, consequently, their lifetime are limited to catastrophic failure (CF). Previously [5] the research of preliminary irradiation by neutrons influence on parameters of IR-LEDs change and CF probability during their further operation have been considered. Moreover only investigation of preliminary irradiation by gamma-quanta influence on emissive power of LEDs decrease during operation has been discussed in [6].

Thus, the purpose of this investigation is to research the influence of preliminary irradiation by ^{60}Co gamma-quanta on CF development in the IR-LEDs during long-term operation. So, in this paper we have researched combined influence of gamma-quanta and long-term operation factors on probability of CF development.



2. Materials and methods

The objects of this investigation were industrial LEDs manufactured on the basis of dual AlGaAs heterostructures with 1 μm active layer grown on the monocrystalline n^+ -GaAs wafer by means of liquid epitaxy. The crystal size was $450 \times 450 \mu\text{m}^2$. Figure 1 represents the structure of the dual AlGaAs heterostructure of the LED.

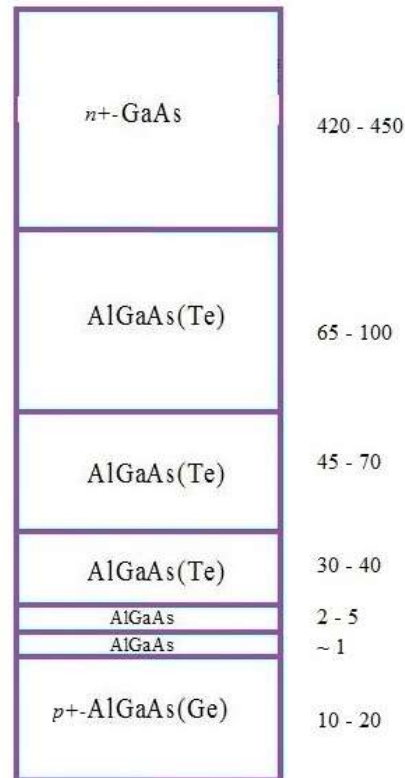


Figure 1. The thickness of the layers of dual AlGaAs heterostructure, microns.

LEDs were manufactured using a standard sandwich technology that involves metallic layer deposition and shaping processes for ohmic contact creation, photolithographic and chemical etching processes for die formation and dicing for wafer division into individual chips.

LEDs had packages and lenses made of an optical compound that was used to form the required angular pattern for output lumen. We emphasize that the preliminary investigation shows us that the optical compound irradiated by gamma-quanta does not lead to changing its optical properties in a given wavelengths range. Consequently, we suggest that the changing of the observable light characteristics of the LEDs is due to the change of characteristics in their active layer only.

In a continuous power mode, the LED forward operating current was $I_{op}=50 \text{ mA}$ and supply voltage was not over $U_{op}=2.0 \text{ V}$. The maximum radiant wavelength was within the range of $0.82 \dots 0.90 \mu\text{m}$.

Three batches of LEDs were composed of 20 items in each group. The first batch (LED-1) was intended for step-by-step tests without preliminary irradiation. The second batch (LED-2) was destined for preliminary irradiation with a dose equal to $D_{\gamma 1}=5 \cdot 10^4 \text{ Gy}$. The third batch (LED-3) was meant for preliminary irradiation with a dose equal to $D_{\gamma 2}=2 \cdot 10^6 \text{ Gy}$. Preliminary irradiation was performed with ^{60}Co gamma-quanta while the LEDs were in a passive power mode, i.e. without adding external electric field.

The doses of preliminary irradiation by gamma-quanta were chosen on the basis of the results previously published in [7,8]. We established that decrease of emissive power of the LEDs irradiation

by gamma-quanta includes three stages. At the first stage, the fall of emissive power of the LEDs is attributed to the radiation-stimulated reconstruction of the initial defect structure of the LED crystal as evidenced by saturation of this stage as the level of exposure increases. At the second stage, the fall of emissive power of the LEDs during irradiation is attributed solely to the introduction of radiation defects. The second stage proceeded to the third stage, distinguished by the LED transition into the field of low level electron injection with further origination of CF.

These results [7,8] allow us to select the doses for preliminary irradiation by gamma-quanta. The first dose of irradiation was chosen because the emissive power reduction under irradiation corresponds to the first stage of the fall of emissive power of the LEDs. The second dose corresponded to the second stage of emission power drop of the LEDs irradiated by gamma-quanta.

On the other hand, we have established in [9] that the decrease of emissive power of the LEDs during operation can also be described by three stages. At the first stage, the fall of emissive power of the LEDs is attributed to the reconstruction of the initial defect structure of the LED under the influence of step-by-step test factors. At the second stage, the fall of emissive power of the LEDs during long-term operation is attributed solely to the introduction of new defects. The second stage proceeded to the third stage, distinguished by the LED transition into the field of low level electron injection with further origination of CF. To sum up, the observable laws of emissive power decrease of the LEDs under the influence of gamma-quanta and long-term operation factors are identical to a large extent.

Thus, we can obtain information about summing influence of gamma-quanta and long-term operation factors on the probability of CF development.

Consequently, in this work, combined (spread out over a period of time) influence of gamma-quanta and long-term operation factors on probability of CF development are investigated.

For every LED, volt-ampere (V - I) characteristics under normal conditions were taken using a measurement complex with spherical photometric integrator which allows measuring the forward voltage within the range of 0...5 V with change of the forward current within the range of 1...500 mA and pitch of at least 1 mA. The error of forward current setting from the given level was $\pm 2\%$ and the error of the forward voltage measurement was $\pm 2\%$.

The mentioned characteristics of LEDs were obtained at the very beginning and after every stage of the investigation. The results were processed by means of methods of mathematical statistics. Every batch of LEDs under investigation was characterized by average values of measured parameters.

Standard certified equipment was used for the experiments, and the baseplate temperature was 65°C, the increment step of current was $I_{\text{step}} = +50$ mA. The operating current of the first stage was 50 mA. The duration of each stage was $t = 24$ h. Furthermore, each stage of the experiments is distinguished by the temperature of the LED active layer, which depends on ambient temperature (i.e. baseplate temperature), LEDs thermal resistance, and consumed electric power.

In addition, the limit step of accelerated tests did not go beyond catastrophic failure (CF) development. Step-by-step tests stopped when CFs exceeded at least 80% of the LEDs in each batch.

3. Results and discussion

3.1. V - I characteristic of initial LEDs

Firstly, consider the initial characteristics of the LEDs, which were measured before irradiation by gamma-quanta and step-by-step tests. V - I characteristic was chosen for control parameter, because changes of V - I characteristic preceded CF. Figure 2 represents typical strongly pronounced s-shaped V - I characteristic of initial LEDs.

The observed change in V - I characteristic (dependence 1, figure 2) of LEDs with supply power increase can be described in the following way. In the area of small voltage (area of small forward current and relatively high resistance of the active layer of LED) typical V - I characteristic of the p-n-junction has a relatively small slope (line 2, figure 2). At supply voltage of approximately 1.2 V, the

parallel connection of dislocations to the p-n-junction of the LED is observed. It leads to total slope increase of V - I characteristic (line 3, figure 2).

Next, an active layer resistance decrease with supply voltage increase is observed. It results in increase of noticeable fall of supply voltage on the series connection ohmic contacts (line 4, figure 2). The reduced slope in the V - I characteristic shows the increase of voltage drop in the ohmic contacts.

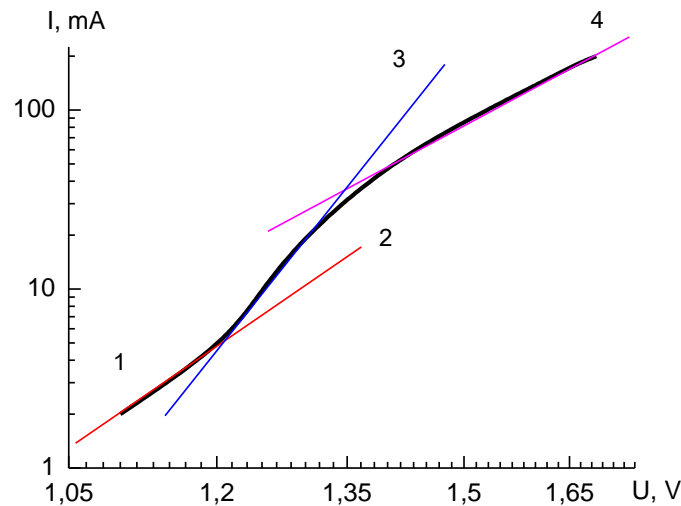


Figure 2. Description of V - I characteristic of initial LEDs: 1 is the measured V - I characteristic, 2 is model description of V - I characteristic before connection of dislocations, 3 is total V - I characteristic of active layer of LED and dislocations, 4 is demonstration of ohmic contacts resistance in the high current area.

Previously we have considered the LEDs with s-shaped V - I characteristic in more detail in [10].

3.2. V - I characteristic of LED-1 batch

Preliminary investigation shows us that the decrease of emissive power of LEDs does not lead to noticeable change of V - I characteristic of LEDs both under irradiation by gamma-quanta and during long-term operation at the influence levels corresponding to the first and second stages of the degradation process.

In addition, previously [9-12] we have established that CF sets measures to reliability of LEDs in these both causes.

Consider the observable changes of V - I characteristic and the CF development for the LED-1 batch. We note that the preliminary irradiation was absent for this batch.

Figure 3 illustrates the change of V - I characteristic of the LEDs during step-by-step tests.

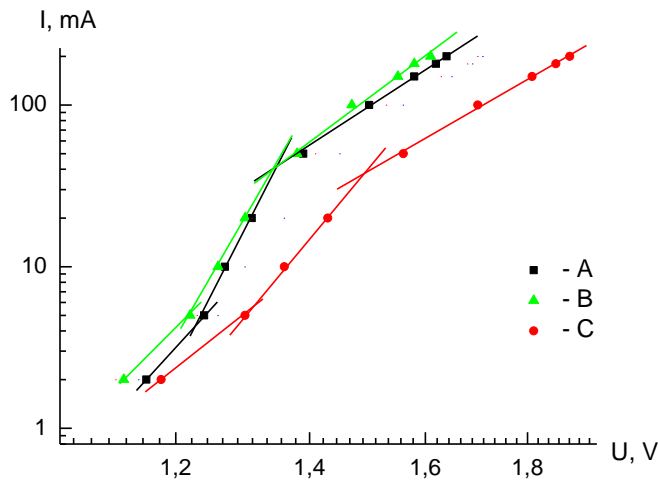


Figure 3. V - I characteristics for the LED-1 batch during step-by-step tests: initial (A); during step-by-step tests (B); before the CF development (C).

The above presented results show that slight changes of V - I characteristic (dependences A and B, figure 3) have been observed during step-by-step tests. We note that the registered changes of V - I characteristic are statistically significant and cannot be attributed to measurement error. At present time, we are unable to explain these changes of V - I characteristic.

Major changes of V - I characteristic have been observed on the test stage immediately prior to CF (dependence C, figure 3) only. This shift of V - I characteristic to the field of higher power supply voltage is accounted to degradation of ohmic contacts resistance, which leads to increase of their ohmic resistance, additional decrease in power supply voltage on the ohmic contacts, their additional heating and CF development at the end.

Consequently, CF probability of LEDs during step-by-step tests is determined by accelerated degradation of ohmic contacts and temperature of active layer of LEDs.

Previously [10-12] we have observed such behavior of V - I characteristic of LEDs, when we researched radiation resistance of LEDs.

3.3. V - I characteristic of LED-2 batch

Let us consider the LEDs batches preliminary irradiated by gamma-quanta. Figure 4 describes the changes of V - I characteristic for the LED-2 batch. The LEDs were preliminary irradiated by ^{60}Co gamma-quanta with a dose equal to $D_{\gamma 1} = 5 \cdot 10^4 \text{Gy}$, which corresponds to the first stage of the emissive power fall under irradiation of LEDs. Figure 4 shows that the strong changes of V - I characteristic are absent. We note that the observable minor changes of V - I characteristics are probably significant. However, at the moment we are unable to interpret them.

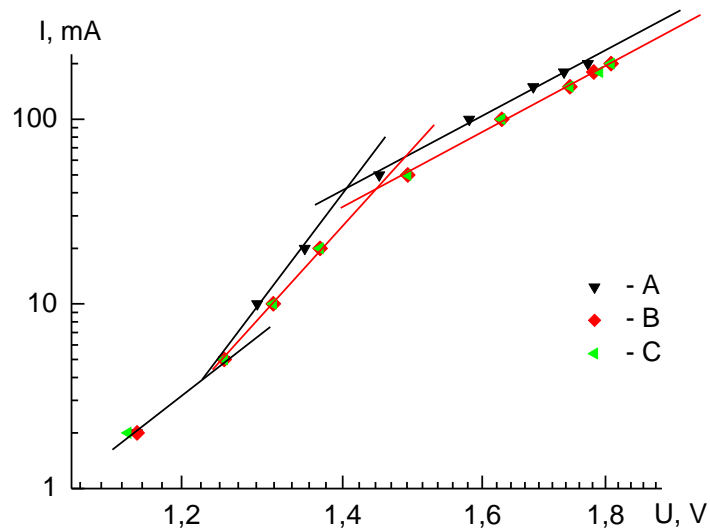


Figure 4. V - I characteristics for the LED-2 batch during step-by-step tests: initial (A); during step-by-step tests (B); before the CF development (C).

Furthermore, comparison of the results shown in this figure with the results presented in figure 3 allows us to conclude that probability of CF development is not aligned with accelerated degradation of ohmic contacts in this case. The CF development is determined by temperature of the active layer of LED only.

So, drop-out (local or full) of the stage of the emissive power fall during step-by-step tests due to reconstruction of the initial defect structure under preliminary irradiation by gamma-quanta provides an opportunity to improve reliability of LEDs by means of ohmic contacts reliability increase. Therefore, such preliminary irradiation by gamma-quanta with the selected dose makes it possible to minimize additional contribution of ohmic contacts to CF probability during step-by-step tests.

3.4. V - I characteristic of LED-3 batch

Consider changes of V - I characteristic of the LED-3 batch during step-by-step tests. Figure 5 depicts a noticeable shift of V - I characteristic to the field of higher power supply voltage by reason of preliminary irradiation by gamma-quanta.

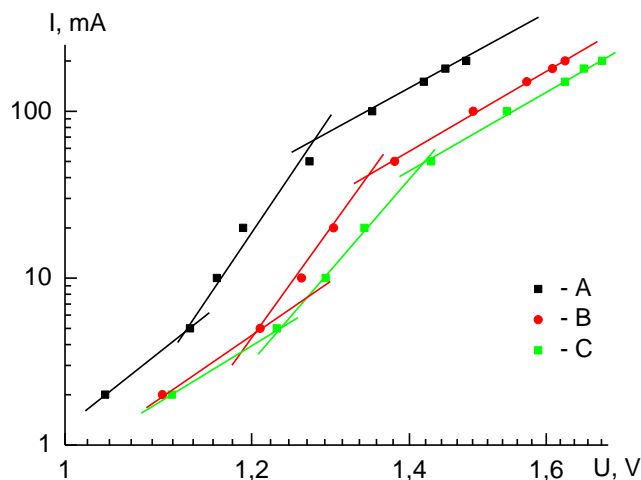


Figure 5. V - I characteristics for the LED-3 batch during step-by-step tests: initial (A); during step-by-step tests (B); before the CF development (C).

Thereby, the selected dose of the preliminary irradiation by gamma-quanta leads to accelerated degradation of ohmic contacts. And the decrease of ohmic contacts resistance has been observed at the stage before CF development only. It can be expected that the given process is due to local annealing of radiation-induced defects under appropriate temperatures which are responsible for degradation of ohmic contacts.

In addition, the results represented in figure 5 allow us to suggest the CF development at the earlier stage of the tests.

3.5. Influence of preliminary irradiation on CF probability

Examine the influence of the preliminary irradiation by gamma-quanta on probability of the CF development. Figure 6 demonstrates the dependence of accumulate quantity of CF on the step number of the tests for the LED batches.

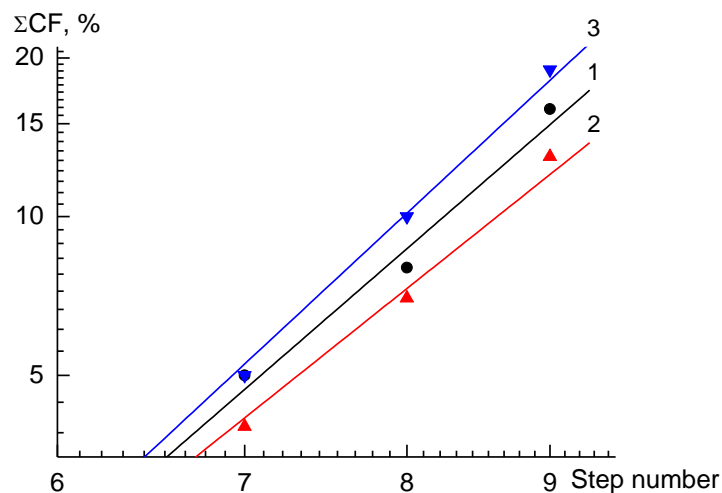


Figure 6. The influence of different doses of preliminary irradiation by gamma-quanta on CF development depending on step number: LED-1 (1); LED-2 (2); LED-3 (3).

This results absolutely confirm the above presented analysis of $V-I$ characteristic changes of the investigated LEDs.

Probability of CF development during step-by-step tests is defined by the increase of ohmic contacts resistance and the temperature of the active layer of LED.

Preliminary irradiation by gamma-quanta with doses corresponding to the radiation-stimulated reconstruction of the initial defect structure of the LED crystal improves ohmic contacts resistance to influence of long-term operation factors. Thus, it leads to decrease of the CF probability at the early stage of step-by-step tests and increases the reliability of LEDs.

Preliminary irradiation by gamma-quanta with doses corresponding solely to the introduction of radiation defects leads to ohmic contacts degradation and increase of CF probability at the early stage of step-by-step tests. Consequently, the reliability of LEDs drops.

These results allow us to recommend the preliminary irradiation by gamma-quanta in the manufacturing technology of LEDs for improvement of their operational characteristics through irradiation with doses in the strictly regulated field of radiation-stimulated reconstruction of the initial defect structure of the LED crystal.

4. Conclusion

Sum up the main investigation results of preliminary irradiation by ^{60}Co gamma-quanta influence on CF development of IR-LEDs based on AlGaAs heterostructure during long-term operation.

1. The investigated LEDs had s-shaped V - I characteristics because of the derived connection of dislocations to the active layer of LED crystal.
2. We have established that the limit step of tests is determined by catastrophic failures due to mechanical destruction of the LED package.
3. The significant changes of V - I characteristic are distinctive under influence of both ionizing radiation and long-term operation factors. The observable changes of V - I characteristic are declarative of accelerated ohmic contacts degradation of LEDs.
4. CF probability of LEDs during step-by-step tests is determined by accelerated degradation of ohmic contacts and temperature of the active layer of LEDs.
5. Preliminary irradiation by gamma-quanta with doses corresponding to the radiation-stimulated reconstruction of the initial defect structure of the LED crystal improves ohmic contacts resistance to influence of long-term operation factors. Thus, it leads to decrease of the CF probability at the early stage of step-by-step tests and increase of the reliability of LEDs.
6. Preliminary irradiation by gamma-quanta with doses corresponding solely to the introduction of radiation defects leads to ohmic contacts degradation and increase of CF probability at the early stage of step-by-step tests. Consequently, the reliability of LEDs drops.
7. Preliminary irradiation by gamma-quanta can be used in the manufacturing technology of LEDs for improvement of their operational characteristics through irradiation with doses in the strictly regulated field of radiation-stimulated reconstruction of the initial defect structure of the LED crystal.

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