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Investigation of Changing Volt-Ampere Characteristics of AlGaInP Heterostructures with Multiple Quantum Wells under Ionizing Radiation

A V Gradoboev[1] and K N Orlova[2]

[1]Open Joint Stock Company National Research of Semiconductor devices, Tomsk, Russia
[2]National research Tomsk polytechnic university, Tomsk, Russia
E-mail: gradoboev1@mail.ru

Abstract. The results of research into degradation of volt-ampere characteristics of light emitting diodes produced on the base of AlGaInP heterostructures with multiple quantum wells are presented on the example of light emitting diodes (emission wavelengths 623 nm and 590 nm) under gamma quantum and fast neutron radiation in passive powering mode. The shifts of volt-ampere characteristics into the higher voltage range have been observed in conditions of increasing neutron fluence and radiation dose. The observed increase in the resistance of ohmic contacts is caused by the rising resistance of adjacent area, which in its turn results from the changing mobility of charge carriers. The latter varies with the growth of introduced defects under irradiation. Two different areas of current generation have been identified. A mechanism of current generation depends on injected charge carriers in the range of mid-level electron injection. Moreover, the range of high electron injection is distinguished by changing resistance of light emitting diode cores alongside with current generation conditioned by charge carrier injection.

1. Introduction

A great number of semiconductor devices based on quaternary compounds AlGaInP have been developed recently and used in nuclear and atomic electronics, in the field of optical signal processing, and in various civil and special facilities [1-4]. As these light emitting diodes (LED) are applied in outer space and other conditions with higher radiation background, researchers are confronted with the issue of determining and predicting the radiation stability of AlGaInP LED. Volt-ampere characteristics are selected as a criterion parameter necessary to identify changes caused by ionizing irradiation in a semiconductor device – in LED produced on the base of AlGaInP heterostructures with multiple quantum wells. These characteristics are viewed as basic criterion parameters used by design engineers and other personnel involved in searching for LED optimal operational conditions, maximum values of supplied voltage and current intensity.

At the present the issue of degrading characteristics of gamma-and-neutron-irradiated LED produced on the base of AlGaInP heterostructures with multiple quantum wells hasn't been sufficiently covered in experimental and theoretical literature. This fact makes investigation of ionizing irradiation exposure on the characteristics of mentioned above diodes relevant both for scientific and practical purposes.

Corresponding author: Gradoboev Alexander Vasilievich, professor, Doctor of Technical Science,
+7 913 866 84 05, e-mail: gradoboev1@mail.ru,
634050, Tomsk polytechnic university, 30 Lenina av., Tomsk, Russia.

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The work is aimed at research into changing volt-ampere characteristics of LED produced on the base of AlGaInP heterostructures with multiple quantum wells under gamma-quantum ^{60}Co and fast neutron radiation.

2. Research objects and methods

LED based on AlGaInP heterostructures with quantum wells were produced by various homeland and foreign manufacturers. The produced crystals were placed into a standard case TO-18. Optical compound was used to make a lens to form a directed radiation beam. According to preliminary research results the optical compound, used for lenses production, does not change its optical properties under gamma-quantum ^{60}Co radiation all over the area of neutron fluence impact, even if the dose of radiation is up to 10^7 Gy. Therefore, all the changes in optical properties of irradiated diodes can be conditioned by changing optical characteristics of LED produced on the base of AlGaInP heterostructures.

A set of diodes was divided into parts, for each of them both a radiation dose and a corresponding interval were determined sequentially, as well as all the mid-measurements were taken and a single dose was identified. The obtained results were compared and no radiation defect annealing was revealed, so, inaccuracy of measurements caused by annealing was somehow minimized.

A facility like with the dose rate (0.1 - 10) Gy per second was used as a source of gamma radiation. Isotope Co60 with the efficient energy of gamma quantums 1.25 MeV is an active element in facilities of this kind. The dose was determined according to the period of radiation, and the data on facility operation at the moment of experiments was taken into consideration. Gy (Si) was used to measure the dose of gamma radiation. The certified volume of radiation zone was 3 liters.

Static and pulse reactors with radiation pulse duration 1.5·10-3s were used as sources of fast neutrons, their energy exceed 0.1 MeV. Neutron exposure level was described by fluence of neutrons Fn, that is the number of neutrons per square centimeter (n/cm2).

Since electric field application can influence greatly on the input rate of radiation-induced defects [5-6], reference structures and devices were always irradiated in conditions of passive mode (without external electric supply). The particle flux was directed perpendicularly to the plane of the substrate in all experiments.

3. Experimental findings and discussion

Let us consider the results of measurement, which were obtained before irradiation of facilities as a part of studying LED produced on the base of AlGaInP heterostructures with multiple quantum wells.

As it has been already mentioned [7-9], volt-ampere characteristic, viewed in semilogarithmic scale, makes it possible to identify mechanism of direct current flowing unambiguously and highlight zones with different injection levels of minority carriers into the active LED layer at forward bias [10-11]. On the straight branch of LED volt-ampere characteristics, made in semilogarithmic coordinates, there are two precise zones (marked I and II in Fig. 1).

While current flows through a LED, minor charge carriers are injected into the LED core. The density of electrons in the conduction band and that one of unfilled levels in the valence band are to be simultaneously high in order to intensify recombination. These conditions can be provided if the level of electron injection is high.

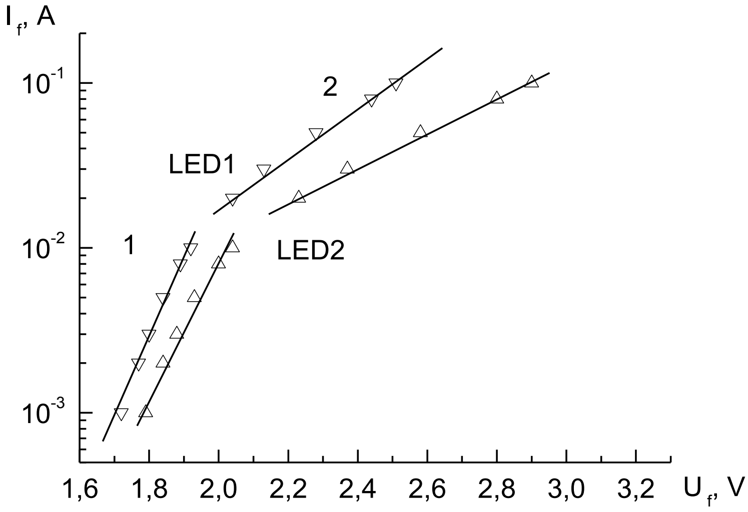

Figure 1. Volt-ampere characteristic of LED in semilogarithmic scale: 1 – mid-level injection zone; 2 – high injection zone; symbols – results of measurement; lines – identified regularities

Approaching the high injection zone the energy of electrons increases in the zone of emitter; Fermi level rises, thus, the height of a potential barrier decreases, so a high level of electron injection can be observed. After injected holes concentration in the diode base and concentration of donors in p-n junction had been approximately assessed, characteristic correlations for mid-level and high injection zones (1) and (2) were confirmed.

$$p \ll N_d \quad (1)$$

$$p \gg N_d \quad (2)$$

Therefore, zones I and II can be considered mid-level and high injection zones, respectively.
The slope of a tangent to the graph and the value of voltage on LED can help to highlight zones, where volt-ampere characteristics depend on various mechanisms of current flowing. There is a straight line on the graph where volt-ampere characteristics are an exponential function. Linear dependence can get lost while switching to high direct currents because of failure on p-n junction or ohmic contact conditioned by thermal effects, change in life span of carriers, conductance channels etc.
The first highlighted zone in Fig. 1 is distinguished by higher angular coefficient of the tangent, which is probably related to injection of charge carriers. Therefore, we can conclude that the first zone is one of electron mid-level injection with predominance of current depending on charge carrier injection.
If current is increased subsequently modulation of LED core is important and determines the second zone of volt-ampere characteristics of reference LED (Fig. 1) with a lower angular coefficient besides electron injection resistance. That is in line with the zone of high electron injection. Therefore, volt-ampere characteristics of LED in high injection zone aren't conditioned by impurity concentration in LED core. If the level of injection is high, properties of a semiconductor in the core are specified mainly by injected carrier concentration. And the resistance of an active layer is similar to the resistance of a semiconductor.
Here we consider results of measured red and yellow LED volt-ampere characteristics under ionizing irradiation, to be precise, fast neutron irradiation, and that is submitted in linear coordinates (Fig. 2). It is worth saying that the decrease in radiation power was $\frac{P_x}{P_0} = 0,1$ under irradiation by fast neutrons with fluence up to $5.06 \cdot 10^{15}$ n/cm2

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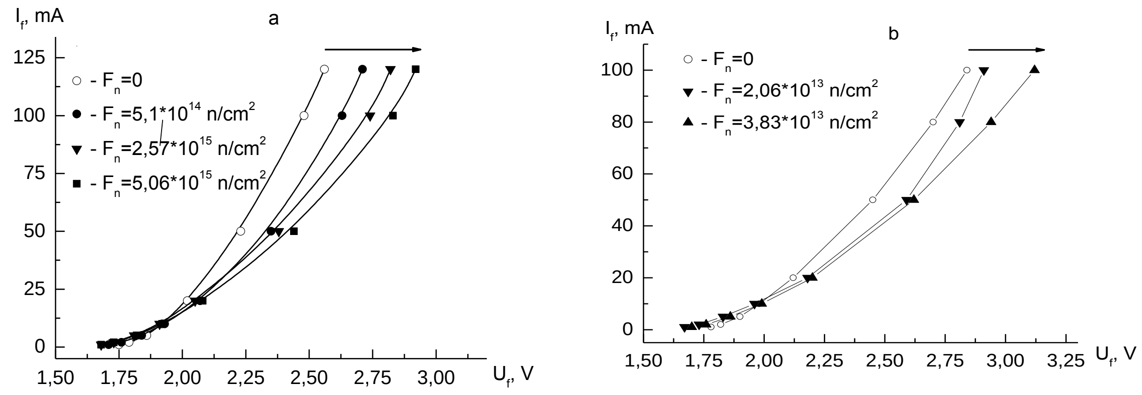

Figure 2. Volt-ampere characteristic of LED produced on the base of AlGaInP heterostructures with multiple quantum wells irradiated by fast neutrons: a) – LED (λ=623 nm); b) – LED (λ=590 nm); symbols – measurement results; lines – identified regularities; arrows indicate the direction of changing volt-ampere characteristics

All the changes in volt-ampere characteristics typical both for LED (λ=623 nm) and LED (λ=590 nm) are observed in the range of high currents. In the range of low currents changes in volt-ampere characteristics are insignificant. Moreover, volt-ampere characteristics are shifted into the higher voltage range because of the increase in neutron fluence. Since the resistance of LED core is minimal in the range of high currents the mentioned above shift can be caused by rising resistance of ohmic contacts. In compliance with information presented in the literature the resistance of ohmic contacts to GaAs materials rises proportionally to the number of radiation-induced defects, dislocations and other structural imperfections. Thus, in the range of considerably reduced irradiation power and high currents, where the shift of LED volt-ampere characteristics was registered, defects are principally radiation-induced and, as the consequence, the resistance of ohmic contacts rises. Furthermore, according to the available data [12], an ohmic contact based on Au-Ge-Ni – n-GaAs has lower irradiation stability than that of GaAs, so its degradation under irradiation it accelerated.

The identified increase in resistance in the range of high currents can't be viewed as rising resistance caused by the crossed junction metal – semiconductor, because alloyed near-to-the-contact layers, which are surfaced on both sides of the diode and reduce the potential barrier, further efficient penetration of electron flowing through material depth. Rising resistance can be probably conditioned by growing resistance of near-to-the-contact zone. The latter results from the changing charge carrier mobility, which depends on the number of radiation-induced defects and other imperfections in solid structure.

Here we consider the change in volt-ampere characteristics of gamma-quantum irradiated LED produced on the base of AlGaInP heterostructures with multiple quantum wells.

Emission power reduction under gamma-quantum 60Co radiation in the dose up to $5 \cdot 10^6$ Gy came up $\frac{P_x}{P_0} = 0,4$.

All the changes in volt-ampere characteristics specific both for LED (λ=623 nm), and for LED (λ=590 nm) are identical to the changes registered for LED produced on the base of AlGaInP heterostructures with multiple quantum wells under irradiation by fast neutrons. In the range of low currents volt-ampere characteristics don't change significantly. There is a shift of LED volt-ampere characteristics into the range of higher voltages in high current area. Although the radiation mechanism of fast neutrons differs from that of gamma-quantums, emission power also reduces significantly in the area of shifted volt-ampere characteristics. It indicates exceptionally radiative nature of defects and confirms the hypothesis of degrading ohmic contacts of diodes. The mentioned structure imperfections

are the reason for changing charge carrier mobility, as the consequence, resistance grows in near-to-the-contact zone of ohmic contact.
The following conclusions can be drawn on the ground of the presented results.

4. Conclusion

1. Mid-level and high injection of charge carries can be clearly highlighted in volt-ampere characteristics of LED AlGaInP with multiple quantum wells (λ =623 nm, λ = 590 nm) before the test of ionizing irradiation influence. Therefore, we can conclude that LED produced on the base of AlGaInP heterostructures with multiple quantum wells operate in the mode of mid-level and high injection.
2. Two areas of different current generation were highlighted according to the slope of volt-ampere characteristics of non-irradiated LED in a semilogarithmic scale. The first zone of volt-ampere characteristics (Fig. 2) is distinguished by the mechanism of current generation in dependence on injected charge carriers in the range of mid-level electron injection, the change in the resistance of LED core and current generation caused by charge carrier injection are important for the second zone of volt-ampere characteristics in the range of high electron injection.
3. The slope of volt-ampere characteristics of LED produced on the base of AlGaInP heterostructures with multiple quantum wells in a semilogarithmic scale is identical in the range of mid-level electron injection. On the other hand, the slope of volt-ampere characteristics rises as the energy gap gets narrower in the range of high electron injection.
4. If LED produced on the base of AlGaInP heterostructures with multiple quantum wells is radiated by fast neutrons with fluence up to до 5.06·1015 n/cm2 its volt-ampere characteristics change insignificantly in the low current range. As the fluence of neutrons increases in the high current range, volt-ampere characteristics are shifted into the range of higher voltages. This shift is possible because the resistance of ohmic contact rises. The increase in resistance is probably conditioned by growing resistance of near-to-the-contact zone. That is the result of changing charge carrier mobility, which varies according to the augmenting number of defects conditioned by fast neutrons.
5. If LED produced on the base of AlGaInP heterostructures with multiple quantum wells are radiated by gamma-quantums 60Co in the dose up to $5 \cdot 10^6$ Gy, the results of volt-ampere characteristics are identical to those, which were obtained under radiation by fast neutrons, that is, the shift of volt-ampere characteristics in the high current area into the range of higher voltages.

References
[1] Modak P *et al.* 2000 *Journal of electronic materials,* **29** 80-85
[2] Dan Sporea 2006 *Proceedings of the Symposium on Photonics Technologies for 7th Framework*, 281-185
[3] Bei Zhang *et al*. 1999 *Proceedings of SPIE,* **3899** 232-238
[4] Chu D Y *et al*. 1993 *IEEE Photonics Technology Lett,* **5** 1353-1355
[5] Gusakov V V, Latyshev A V, Stelmakh V F 1990 *News of Higher Educational Institutions. Physics*, 15 – 30
[6] Grusha S.A. *et al*. 1990 *Electronic engineering. Series 2. Semiconducting devices,* **5** 68-72
[7] Nikiforov S G Dissertation … candidate of engineering 2006 Moscow 158 p
[8] Orlova K. N. , Gradoboev A. V. 2012 *Proceedings of IFOST - 2012*, **1** 192-195
[9] Orlova K N. , Gradoboev A V. 2014 *Proceedings of CriMiCo 2014* 874-875
[10] Gradoboev A V, Orlova K N 2015 *Phys. Stat. Sol. C* **12** No.1-2 35-38
[11] Gradoboev A V and Orlova K N 2014 *Advanced Material Research* **880** 237
[12] Gradoboev A V Surzhikov A P 2005 *Radiation stability of GaAs microwave devices Tomsk* (Izdatelstvo TPU) 277p