

Deterioration of Watt and Voltage Characteristics of AlGaInP Heterostructures under Irradiation by Fast Neutrons

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Abstract. The paper presents the results of studying characteristic deterioration of AlGaInP heterostructures with multiple quantum wells. The research was completed for light emitting diodes (emission wavelengths 623 nm and 590 nm) under fast neutron irradiation in passive mode. It has been revealed that the change in emission power and operating current under irradiation is conditioned by band gap and level of electron injection. Here, the change of current flowing mechanism is a distinctive parameter of the boundary between the first and second stages of emission power reduction caused by fast neutron irradiation of AlGaInP heterostructures ($\lambda=625$ nm).

1. Introduction

In recent years the sphere of applying optoelectronic devices has been widened significantly due to rapid development of optoelectronics, which is grounded on the aggregate of optical and electronic properties of materials necessary to generate and transform, store and memorize information, due to the unique properties characteristic exclusively for optoelectronic devices. The following list represents only some fields of application:

- fiber-optic systems [1];
- optical signal processing [2-4];
- photoconverters and solar batteries;
- laser printers;
- traffic control devices and road signs on highways;
- movable information boards;
- car lamps;
- sea and river markers;
- and components of train and aircraft board equipment etc. [5].

The base of any optoelectronic system is a source of emission, and its properties determine characteristics of the device. The incoherent radiation source is a light emitting diode. High-performance light emitting diodes produced on the base of aluminum-gallium-indium-phosphide heterostructures (AlGaInP or InGaAlP, AlInGaP etc.) have been developed recently. They are the most effective ones in the visible region, for instance, in red, orange and yellow ranges. These four-component semiconductor heterostructures according to the order of named chemical elements are different, being a single physical entity though, and the order of designation depends

mainly on the amount of substance of a given chemical element.

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AlGaInP heterostructures with multiple quantum wells are produced by metalorganic chemical vapor deposition (MOCVD)-based gaseous epitaxy [6-9]. However, a number of technological problems in production of heterostructures have not been solved yet. These are as follows: hydrogen passivation, timely oxygen removal from the case, decrease of imperfection on heteroboundaries of layers and improvement of grown layer homogeneity. The presented facts are to be taken into consideration for studying radiation-induced defects in the given heterostructures and devices made of them.

Quantum wells, introduced into the active area of a heterostructure, facilitate concentration growth of minor charge carriers in it due to the state of two-dimensional electronic gas; it increases internal quantum efficiency [4]. Here, relaxation of arising on the boundary of layers resilience conditioned by discrepant lattice parameters under quantum well introduction into the core of AlGaInP heterostructures doesn't lead to dislocations or point defects, which can be centers of non-radiative recombination.

At present, the change in parameters of AlGaInP heterostructures with multiple quantum wells exposed to ionizing irradiation has not been adequately investigated [10-11]. The issue of radiation stability of light emitting diodes produced on their base is gaining its urgency because they can be used in conditions of various ionizing irradiation [12-13].

2. Research objects and methods

The objects of research were red light emitting diodes (LEDR) produced on the base of AlGaInP heterostructures with multiple quantum wells ($\lambda = 623$ nm) and yellow (LEDY) ones ($\lambda = 590$ nm). Therefore, the diodes under investigation were distinguished by the broad band gap, that is, composition of the core. Some studied heterostructures were produced as ready-made crystals, while others were heterostructures used for batch production of crystals in similar manufacturing processes.

At first, a p-layer of the structure was dielectrically SiO₂ coated (0.5 μ m) and a part of the substrate was chemically and chemical-dynamically etched to obtain the total thickness of the structure (200-210 μ m).

Then an ohmic contact was formed towards n-GaAs substrate all over the surface of plates via magnetron-coated AuGeNi+Au deposition (0.15-0.2 μ m). An ohmic contact was burnt into in the atmosphere of hydrogen at temperature (425-430) °C for 5 min. Finally, the plates were glued onto ceramized substrate and cut by the disk in several crystals (chips). Dimensions of crystals after cutting are 1020x1020 μ m.

Batch produced in this way crystals were mounted into corresponding cases via thermal-compression assembly. For this purpose metallic cases were used (KI1 and KI2, they differ in geometric dimensions).

One of the mostly applied type of ionizing irradiation to carry out radiation tests on simulating facilities is neutron flux, its effect bases on crystal lattice displacement.

The purpose of the work is to investigate deterioration of watt and volt characteristics of AlGaInP heterostructures with multiple quantum wells under fast neutron radiation.

For the purpose of research different LED sets were made, and each set included at least 10 diodes. For various LED sets exposure level was augmented via sequentially increased radiation dose. LED were irradiated in standard conditions in passive powering mode, that is without direct current flowing.

In all the experiments focused on irradiation particle flux was directed perpendicularly to the substrate plane. The degree of impact under irradiation was described in terms of neutron fluence F_n [cm⁻²]. Watt and volt characteristic was measured before and after irradiation in a sphere. Each experimental value of the below given dependences conforms to a mean parameter value for LED set.

We applied both one-time and sequential sets of required levels of exposure. There is no difference in the results obtained this way so we can conclude that methods to measure the change in LED parameters don't cause annealing of introduced radiation defects.

3. Experimental findings and discussion

Watt and volt characteristics are ones of main LED characteristics, which determine operating features of an electronic appliance. Relying on the analysis of watt and volt characteristics optimal parameters of appliance maintenance can be selected including voltage, which provides maximum external LED quantum efficiency.

As fast neutron fluence was increased the change in watt and volt characteristics was registered. However, at first, let us consider measurement results relevant for studying non-radiated diodes. Typical watt and volt characteristics of the non-irradiated diodes under consideration are shown in Fig. 1.

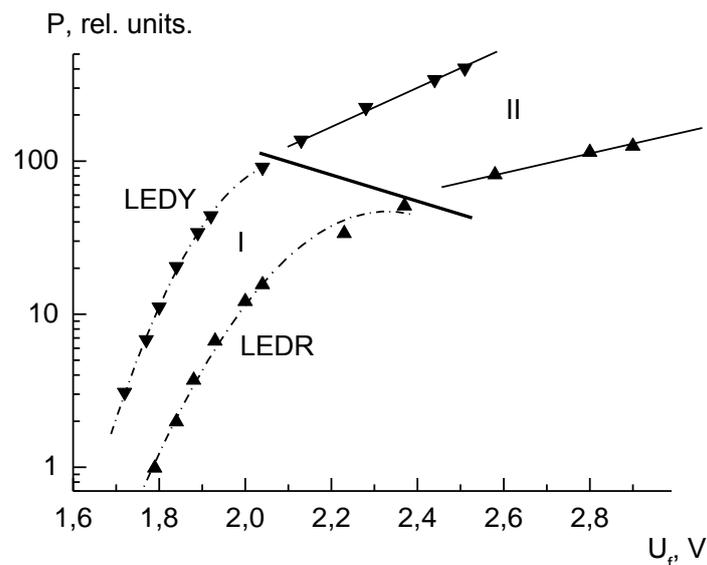


Figure 1. Watt and volt characteristic of reference light emitting diodes symbols – measurement results; lines – identified; I – mid-level injection zone; II – high injection zone

As one can see, two zones are highlighted for reference diodes, and there is a boundary between them. Each pronounced zone has its specific dependence of analyzed regularities. First, marked differences of obtained watt and volt characteristics of non-radiated red and yellow diodes are worth mentioning. These differences are conditioned by various band gaps of red and yellow heterostructures and, as the consequence, quantum efficiency (or quantum output) and LED efficiency factor are different:

$$\eta_q = \frac{N_{ext}}{N_{int}} = \eta_e \times \eta_s \quad (1)$$

where η_q – external quantum efficiency,
 N_{ext} – flow of emitted photons,
 N_{int} – flow of recombined photons,
 η_e – efficiency factor of emission output,
 η_s – efficiency factor of light emission.

Therefore, LED external quantum efficiency depends on the sort of material, technology, and rate of emitting and full recombination of charge carriers, life time of radiative and non-radiative recombination. More efficient LED (LEDY in our case) is distinguished by shorter lifetime of minor charge carriers.

Two typical zones (zone I and zone II) can be highlighted for each LED type according to obtained watt and volt characteristics. We can sum up that highlighted zones are those of mid-level and high electron injection. The frontier between mid-level and high electron injection is specified by equal concentration of injected electrons and holes in p-region. Our assessment has revealed that

concentration of injected electrons is really comparable with concentration of holes in p-region in conditions of the identified frontier.

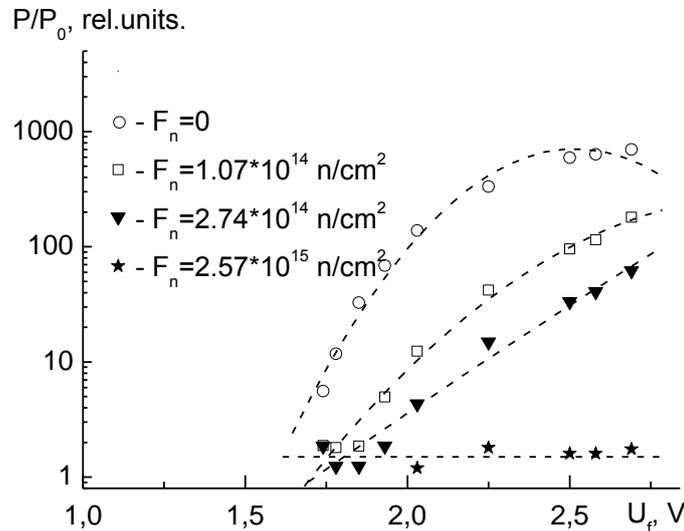


Figure 2. The changes in watt and volt characteristics of LEDR under fast neutron irradiation: symbols – experimental data; lines – identified regularities

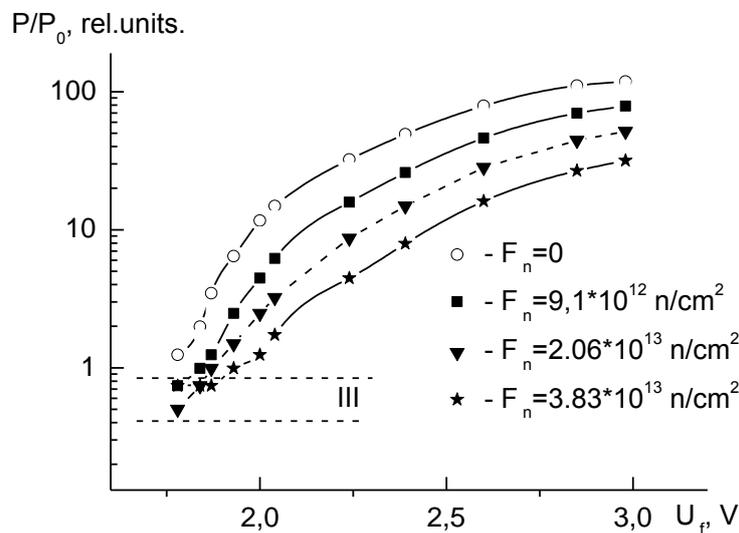


Figure 3. The change of watt and volt characteristics of LEDY under fast neutron irradiation: symbols – experimental data; lines – identified regularities.

Fig. 2 demonstrates the change in watt and volt characteristics of LEDR heterostructures under fast neutron irradiation. As one can see zones of mid-level, high and low injection of electrons into the core of a heterostructure are highly pronounced and confirm the drawn conclusions for non-radiated LED. The zone of low electron injection (III) allows deducing an inference that final phase of

reducing emission power is conversion into a low electron injection mode for which dependence of emission power on operating current is not relevant.

Two typical stages of reducing emission power (bright and dark symbols in Fig. 2) differing in the mechanism of current flowing can be highlighted on the base of presented above results. All identified regularities are confirmed by accuracy of approximation more 99.9%.

Then, one can assume that the first stage of reducing LEDR emission power doesn't correlate with introduced centers of non-radiative recombination, while the second stage is conditioned by them, therefore, principles of current flowing are changed. Here, reducing at the first stage emission power of the core under fast neutron irradiation accounts for introduced absorption centers of generated irradiation, which are irrelevant for current flowing. These absorption centers can be located both in the core and adjacent layers, and in view of technological peculiarities of AlGaInP heterostructures production principles of absorption centers can be caused by mentioned above impurity compounds. The main difference of studied watt and volt characteristics of yellow light emitting diodes under fast neutron irradiation (Fig. 3) is unchanged mechanism of current flowing in conditions of first – second stage conversion of reducing emission power under fast neutron irradiation. Here reducing emission power can result from absorption of irradiation emitted by the core in adjacent layers.

4. Conclusion

In conclusion we sum up main results of investigation into deterioration of watt and volt characteristics of LED produced on the base of AlGaInP heterostructures ($\lambda_1 = 590$ nm and $\lambda_2 = 630$ nm) with multiple quantum wells under fast neutron irradiation:

- Quantum efficiency of LEDY and LEDR depends on the band gap, rate of non-radiative and complete recombination, life time of minor charge carriers.
- The change in emission power under irradiation is dependent on the band gap and level of electron injection.
- While conversion from mid-level to high level injection of electrons the mechanism of current flowing changes as the result of fast neutron irradiation of red LED produced on the base of AlGaInP heterostructures.
- The increased irradiation dose causes more pronounced differences between mid-level and high electron injection, but the mode of low electron injection is a final stage of the reducing emission power process.
- The mechanism of current flowing is not changed while conversion of mid-level injection into high injection of irradiated by fast neutrons LEDY.
- Unsoundness of reference heterostructures, that is occurrence of special impurity compounds, is relevant for arising absorption centers and influences on the current flowing mechanism through a LED. Thus, unsoundness of reference heterostructures has significant impact on efficiency of reference LED and its radiation stability. The higher efficiency of LED is the higher is its radiation stability.

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