Transition in AlGaInP heterostructures with multiple quantum wells during fast neutron radiation

A V Gradoboev, K N Orlova
National research Tomsk polytechnic university, Tomsk, Russia

E-mail: gradoboev1@mail.ru

Abstract. Radiation exposure causes degradation of semiconductors' structures as well as different semiconductors based on these structures. The purpose of the research work is to study transitions in AlGaInP heterostructures with multiple quantum wells during fast neutron radiation Objects of the research are 590 nm and 630 nm LEDs based on AlGaInP heterostructures. It is proved that LEDs′ radiant power decrease occurs within three periods: during the first period radiant power decrease is caused by radiation stimulated structural adjustment of a primary defect structure; during the second period the decrease is results from radiative defects introduction; with further enhancement of radiation exposure the second period develops into the third period, where LEDs evolves into the mode of electrons low injection into an active region. Empirical relations explain radiant power changes within each period are presented. Region of transitions between the first and the second periods that cause radiant power partial recovery are specified. Transitions occur both directly and indirectly for heterostructures. Potential causes of transitions occurrence are being discussed.

1. Introduction

Microelectronic articles are utilized in different conditions. More specifically, they serve in outer space, in upper atmosphere and at nuclear energy centers [1-3] being subjected to different kinds of ionizing radiation. As ionizing radiation takes place, different radiation effects are introduced into active layers of microelectronic articles, which change articles specifications and finally cause their break-down. These result in academic interest toward ionizing radiation effect on microelectronic articles.

AlGaInP heterostructures with multiple quantum wells are widely used in design and serial production of visible LEDs for different wavelengths. The fact that volume of active layers of heterostructured LEDs with quantum wells decreases makes it reasonable to suppose that they are more stable to ionizing radiation effect. This in conjunction with expected higher photoresponse determines academic interest to heterostructures.

Radiant stability of AlGaInP heterostructured LEDs with multiple quantum wells is being investigated and there are some recent papers with experimental findings [4-7]. In particular some researchers [7] present their experimental findings in the problems transitions in AlGaInP heterostructures with multiple quantum wells being subjected to gamma-quantum radiation. Those experimental findings allow anticipating alike effects in other conditions.

The purpose of the research work is to study transitions in AlGaInP heterostructures with multiple quantum wells during fast neutron radiation.

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

2. Research objects and methods

Several lots of LEDs produced on the base of different AlGaInP heterostructures with multiple quantum wells and 1,8-2,0 µm thickness of active layers which were obtained from different sources and meant to produce LEDs with 590 nm wavelength (LED 1) and 630 nm wave mode (LED 2).

LEDs were fabricated through the standard sandwich technology where deposition techniques and layer metallization to form ohmic contacts are applied; photolithography and chemical etching to form crystals (chips) as well as scribing to divide wafers into separate chips were used. LEDs had corpses and lens elements to form necessary diagram of light flux directivity from optical compound. According to the preliminary research data optical compound used to fabricate lenses does not change its optical properties even at $F_n = 2\cdot10^{14}$ cm^{-2} fast neutron radiation. From there all changes of LEDs′ optical properties resulted from radiation within the mentioned above fast neutrons transfer might be considered as conditioned by changes of diodes active region optical properties.

LEDs in some lots had an identical structure of a crystal and approximately alike sectional area of an active region. Each lot contained 20 LEDs. When battery mode was continuous the intensity of forward operating current of LEDs under review made I_{op} = 100 mA, for this purpose voltage supply did not exceed U_{op} = 3 V.

Watt-ampere specification of each LED before and after radiation were measured. Measurements in a blob do not depend on LEDs′ orientation. This fact allowed to provide each individual LED with radiation measurement repeatability with less than ± 2,5% deflection for (1-200) mA.

Data obtained were analyzed by mathematical statistics technique. Each lot of LEDs was classified by average measured values. Dispersion in the radiation power in primary LEDs did not exceed ±10%, but it increased after fast neutron radiation up to ±15%.

Fast neutron radiation was delivered in passive battery mode without operating current, while fast neutron impact level was characterized by F_n (cm^{-2}) particle transfer.

Each lot of LEDs was provided with a sequential number of fast neutron transfers with each definite pitch up to full break out of more than 80% of LEDs in a lot. Results from the analysis of different lots of LEDs with different fast neutron transfer and watt-ampere specification measurements make it possible to prevent any radiation defects annealing during measurement. Therefore an observable change of radiant power is determined by fast neutrons impact only.

3. Experimental findings and discussion

Observation of radiant power decrease of different lots of subjected to fast neutron radiation LEDs proves that each lot under consideration undergoes transitions identical to those that were observed earlier in the conditions of gamma-quant radiation [7] at the boundary of the first and the second periods of radiant power decrease. All AlGaInP heterostructures can be precisely divided into two specific groups. The first group is formed by heterostructures with direct transitions. Consequently, the second group is formed by heterostructures with indirect transitions. Alike results were observable in both LED-1 and LED-2 lots.

In the first instance it is necessary to study the findings obtained during the investigation of indirect transitions. Figure 1 shows a relative radiant power change of LED-1 lot measured at 100 mA operating current during fast neutron radiation. The same results occurred with LED-2 lot. .

Radiation model [8] is the most relevant to describe experimental findings. Data presented in figure 1 show that process of power decrease can be described through three periods.

During the first period radiant power decrease occurs as a result of radiation-stimulated reconfiguration of present defect structure what allows explaining the period finiteness (radiant power decrease process saturation). In this case radiant power decrease is described with the following equation:

$$\frac{P_F}{P_0} = 1 - A\cdot\left[1-\exp\left(-C_1\cdot F_n\right)\right] \quad (1)$$

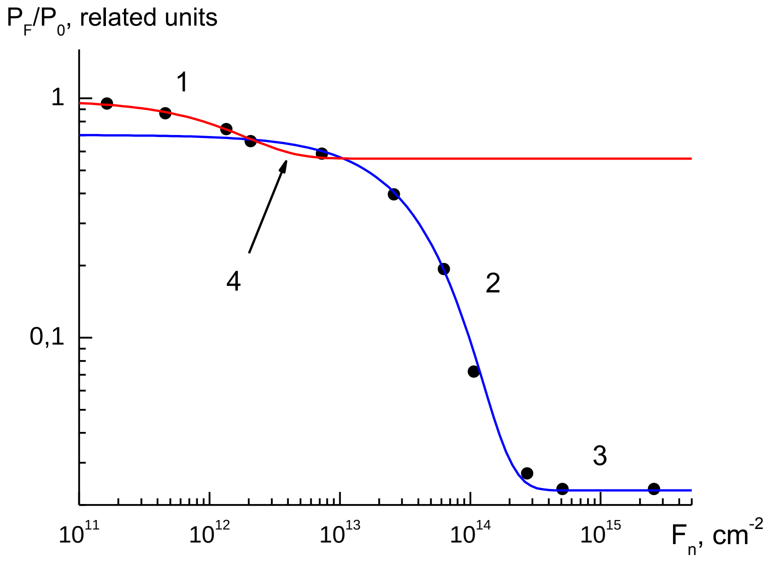

Figure 1. LED-1 (I_{op}=100 mA) radiant power change when radiated with fast neutrons: symbols – experimental data; lines – determined relations; 1, 2, 3 – determined periods of radiant power decrease; 4 – transitions region

where P_F, P_0 – radiant power with I_{op} = 100 mA, measured before and after radiation consequently; A – coefficient of proportionality that characterizes the first period input into the overall radiant power decrease when radiated with fast neutrons; C_1 – damage coefficient that specifies the speed of radiant power decrease during the first period at neutron transfer growth [cm^2].

The second period is characterized by LEDs′ radiant power change with neutrons transfer growth that occurs due to the radiation defects and is described with the equation

$$\frac{P_F}{P_0} = \frac{P_{min}}{P_0} + B \cdot \exp\left(-C_2 \cdot F_n\right) \qquad (2)$$

where P_{min} – LED s′ radiant power with low injection of electrons into its active region without any dependence from current flow; B – coefficient of proportionality that characterizes the second period input into the overall radiant power decrease when radiated with fast neutrons; C_2 – damage coefficient that specifies the speed of radiant power decrease during the second period at neutron transfer growth [cm^2].

The third period corresponds to LED s′ fast neutron radiation limiting value. LEDs occur in a mode of low injection of electrons into its active region. Radiant power is described in the equation

$$P_F = P_{min} \qquad (3)$$

During the third period radiant power decrease, the majority of LEDs catastrophically break down.

More precise comparison of 1-3 formulae and results, presented in Table 1, makes some discordance observable. The second period starts with some higher level of LED s′ radiant power, than it comes from formula (1).

In particular, from formulae (1,2) goes the following formula

$$A + B = 1 \tag{4}$$

Actually, results from Table 1 and equations we have

$$\delta\left(P_F / P_0 \right) = (A + B) - 1 \geq 0 \tag{5}$$

Earlier investigations [7] in AlGaInP heterostructured LEDs′ radiant power decrease when radiated with gamma-ray quantum proved that at the edge of the first and the second periods of power decrease some transitions occur. These processes result in partial recovery of radiant power. At this LEDs′ radiant power at the edge of the first and the second periods were observable in an explicit form.

In this research radiant power growth $\delta\left(P_F / P_0 \right)$ on the edge of the first and the second periods can also be explained by alike transitions with partial recovery of radiant power which are not observable in an explicit form. Statistical analyses of experimental findings showed that observable value is statistically significant and reproducible in series of experiments.

Same results were obtained at different volumes of operating current, with other heterostructures (LED-2). At this the higher operating current the more explicit transitions at the boundary of the first and the second periods.

Earlier alike transitions at the boundary of the first and the second periods of radiant power decrease during gamma-quant radiation were noticed among identical heterostructures [9].

It is necessary to study transitions, observable directly in heterostructures subjected to fast neutron radiation (second group of heterostructures). Figure 2 shows the way radiant power of LED-1 and LED-2 changes during fast neutron radiation in case of the above described direct transition. Experimental data of radiant power measured at different values of operating current are presented.

It is clearly seen that at the boundary of the first and the second periods of radiant power decrease transitions, which are characterized with partial radiant power recovery against general decrease explicitly occur. It is also seen that radiant power recovery degree depends on operating current volume. Such dependence was observed earlier during the study of heterostructures from the first group.

Consequently, the existence of transitions between the first and the second periods of radiant power decrease during fast neutron radiation for all AlGaInP heterostructures with multiple quantum wells meant to be used in 590 nm и 630 nm wave mode LEDs production is proved. Transitions can occur both directly and indirectly.

Experimental findings prove that transitions relate with the final period of radiation stimulated restructuring of a primary defect structure in a LED′s active layer. It is possible to suppose that in the region of fast neutron transfer action present defects transform into some complexes with radiation defects, which are not the centers of radiationless recombination. In this case, partial transformation of primary defects (centers of radiationless recombination) into such complexes might explain partial recovery of LEDs′ radiant power in the region of transitions under consideration. Dependence of the observed effect of LEDs′ radiant power recovery from operating current volume also makes it possible to suppose that the obtained complexes are electrically active.

Further research in the problems of deep centers spectrum changes in the region of observed transitions during fast neutron and gamma-quant radiation are of great importance.

Comparative study of radiant power recovery in the region of observed transitions and deep centers spectrum changes might give answers to the questions of found transitions nature.

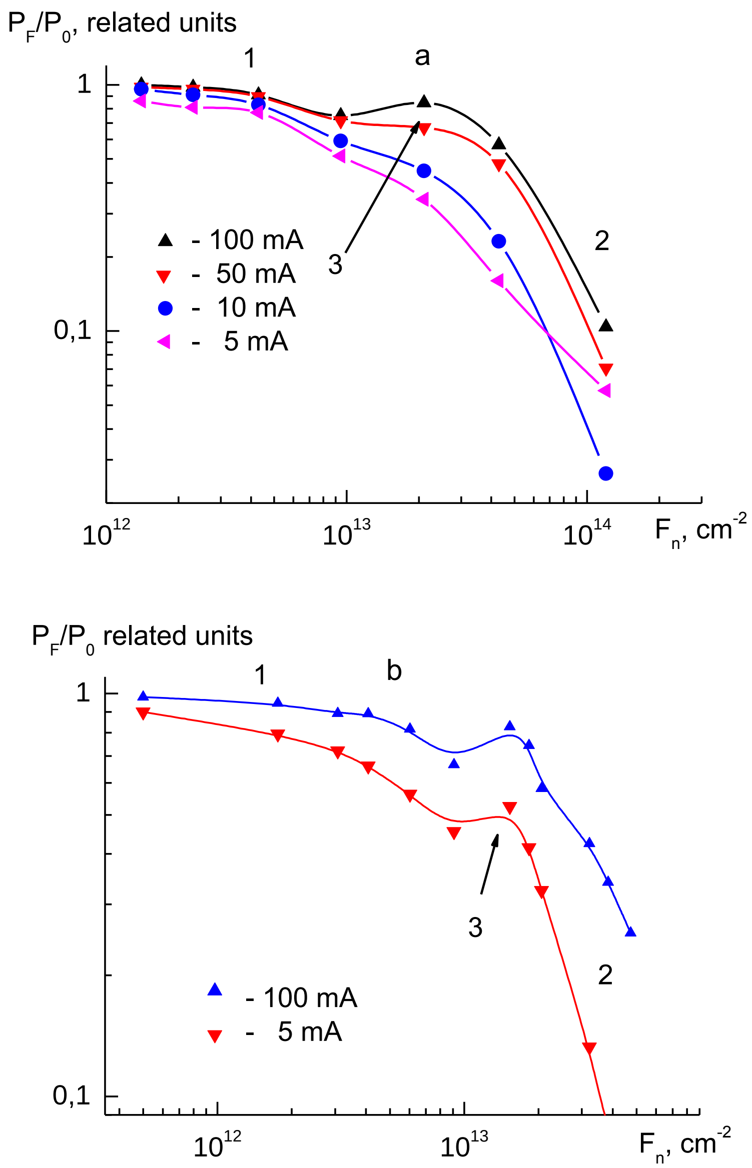

Figure 2. Radiant power changes of LED-1 (a) and LED-2 (b) with explicit transitions during fast neutron radiation: symbols – experimental data; lines – determined relations; 1, 2 – determined periods of radiant power decrease; 3 – transitions region

4. Conclusion

Radiant power decrease of LEDs based on AlGaInP heterostructures with multiple quantum wells during fast neutron radiation in a passive powering mode undergoes three periods: during the first period radiant power decrease occurs due to radiation stimulated restructuring of primary structural defects; during the second period it results from radiation defects introduction; during the third period LEDs go into the electron low injection mode and its radiant power does not depend on operating current volume. Within the third period of radiant power decrease, the majority of LEDs catastrophically break down during watt-ampere characteristic measurements.

Relations that allow describing radiant power decrease within each period are determined. These relations might be used to forecast LEDs′ radiation stability.
For the first time it was experimentally proved that during fast neutron radiation in a passive mode transitions occur at the boundary of the first and the second periods. These transitions are characterized by partial recovery of radiant power against its general decrease. Radiant power recovery degree depends on operating current volume.
Radiant power recovery in the region of transitions might be both direct and indirect depending on AlGaInP heterostructure utilized to produce LEDs with different radiation wave mode.

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