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The fast neutron irradiation influence on the AlGaAs IR-LEDs reliability

A.V. Gradoboev [a,b], K.N. Orlova [a,*], I.A. Asanov [b], A.V. Simonova [a]

[a] National Research Tomsk Polytechnic University, Russia
[b] Research Institute of Semiconductor Devices, Russia

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ABSTRACT

This paper represents the results of investigation of preliminary fast neutron irradiation influence on reliability of IR-LEDs manufactured on the basis of AlGaAs heterostructures. It is determined that design margin of LEDs is defined by catastrophic failures that are driven by mechanical destruction of LED packages rather than their lighting technology characteristics. The upper and lower limits of catastrophic failure probability are determined. In addition, the upper limit is shown to be dependent on the melt temperature of ohmic contact used to fix the chip to chip carrier. The preliminary fast neutron irradiation leads to the shift of defined temperature limits while the probability of catastrophic failure grows with neutron fluence that can be explained by lower radiation resistance of ohmic contact.

1. Introduction

IR-range light emitting diodes (LEDs) manufactured on the basis of AlGaAs heterostructures are used widely as components of various electronic circuits [1–2]. Depending on the usage environment, LEDs may be subject to radiation factors of many types. That is why scientists are interested in investigation of LED radiation resistance [3–5]. On the other hand, LED reliability is one of the most important performance characteristic. At the moment, LED radiation resistance and reliability are considered separately from each other [6–11]. In addition all important tests and analyses associated with reliability and radiation resistance are conducted for different LED samples.

The defect introduction resulting both from irradiation and influence of long-term usage factors leads to LED key parameters degradation. This allows us to suppose clearly that there is combined (complex) impact of ionizing radiation and long-term usage factors. In this case, combined impact stands for simultaneous influence of 2 or more factors, and complex impact stands for spread over time influence of 2 or more factors [5].

Therefore the investigations of ionizing radiation influence on LED reliability characteristics are really of great interest.

The main fundamental damage mechanisms of microelectronic devices at the ionizing radiation high-level are displacement damage and ionization effects. The ionization mechanism is a generally consequence of the gamma-rays dose impact and other charged particles. The lattice displacement caused in the solid state is mainly by neutrons, which were selected as a model ionizing radiation source. The purpose of this paper is to investigate the influence of fast neutron irradiation on the reliability of IR-LEDs.

2. Material and methods

The objects of this investigation are serial LEDs manufactured on the basis of dual AlGaAs heterostructures with 5 μm active layers grown on the monocrystalline n-GaAs wafer by means of liquid epitaxy. Fig. 1 shows the structure of used heterostructure.

LEDs are manufactured using standard sandwich technology (in the serial production) that involves metallic layer deposition and shaping processes for ohmic contact creation, photolytographic and chemical etching processes for die formation and dicing for wafer division into individual chips. LEDs have packages and lenses made of optical compound that are used to form the required angular pattern for output lumen. The crystal size was 450 × 450 μm2. The investigated LEDs are serial LEDs of wide application, including special purpose. Ohmic contact to n-GaAs has been made on the (Au-Ge-Ni) basis, and for AlGaAs-layer on the (Au-Zn) basis.

In continuous power mode the LED forward operating current I_{op} = 50 mA and supply voltage U_{op} was not more than 3 V. The maximum emission wavelength was within the range of 0.82…0.90 μm. Fig. 2 shows the LED structure with all necessary notes.

The object of investigation choice is dictated by the fact that LED structure presented in Fig. 2 is a basic structure for a number of IR-

* Corresponding author.
E-mail addresses: gradoboev1@mail.ru (A.V. Gradoboev), kemsur@rambler.ru (K.N. Orlova).

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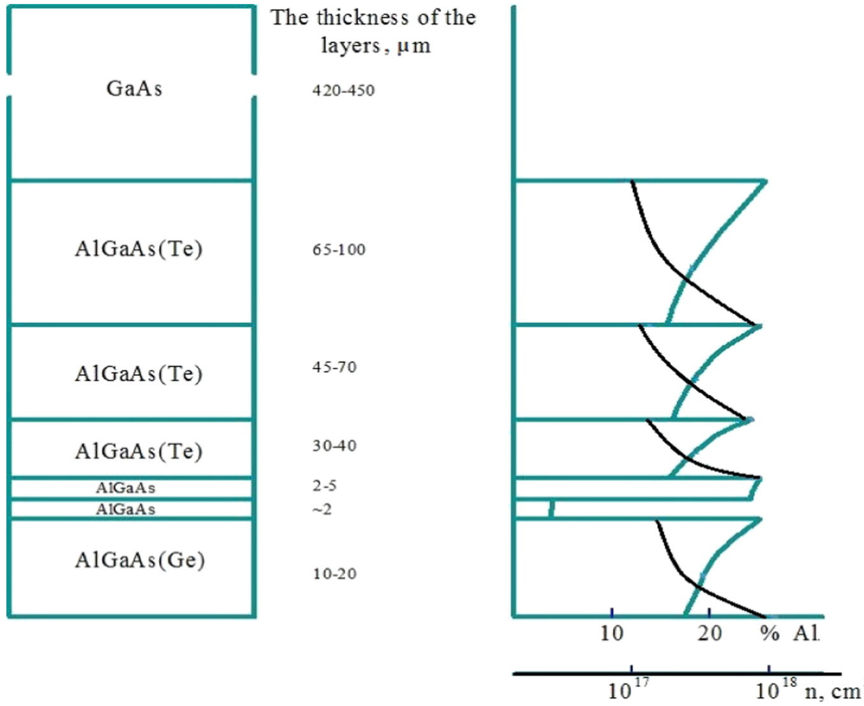

Fig. 1. The double AlGaAs heterostructure, used for the LEDs manufacture.

LEDs, so we can say that in terms of LED structure measured results are also valid for LEDs of other ratings.

For every LED forward and back current-voltage characteristics and watt-ampere ball characteristic under normal conditions were taken. Radiation spectrum was measured for individual diodes at random. The named characteristics of LEDs were obtained at the very beginning and after every stage of the investigation. Obtained results were processed by means of methods of mathematical statistics. Every batch of LEDs under investigation was characterized by average values of quantified parameters. For original LEDs the emissive power spread value didn't exceed ±10% while forward voltage variation at the operating current was not more than average value ±0.15 V. After preliminary irradiation with fast neutrons the emissive power spread expanded up to ±15%. These results allow us to determine lack of significant changes in radiation spectrum, so they are not considered below. For the catastrophic failures analysis an optical microscope «LEITZ SM-Lux» is used.

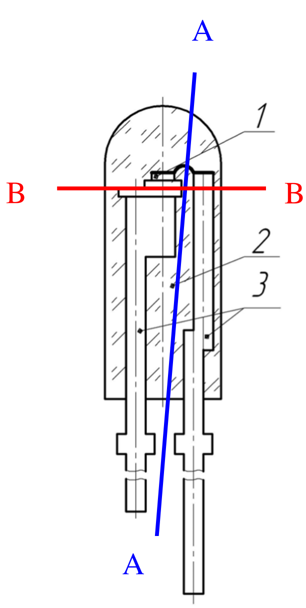

Fig. 2. The construction of LEDs under investigation: 1 – chip; 2 – package and lens made of optical compound (package diameter 2 mm); 3 – chip voltage supply pins; A–A – plane of package mechanical destruction at chip temperature within the range of 260–300 °C; B–B – plane of package destruction at chip temperature within the range of 300–320 °C.

To reduce time of investigation LED reliability was characterized by design margin determined by step-by-step testing under increased temperature. Step-by-step testing consists in conducting tests in LED active power mode under constant ambient temperature during certain stage time, then conducting measurements, and repeating tests with incrementing of operating current by the value of stage increment. In carrying out step-by-step testing mode investigated LEDs placed on a massive heat sink, the temperature of which was set by an external control. The heat sink temperature was set by how the ambient temperature. The ambient temperature did not differ from the air temperature in the test chamber. In the transition to a new testing stage heat sink temperature installed considering of overheating due to LEDs connection. This procedure (given ambient temperature establishment) carried out before the beginning of a new test stage and take no more than 10–12 min in time. This chain of operations is repeated until the failure of 80% of LEDs under investigation.

Now consider named step-by-step testing modes in detail. The ambient temperature during step-by-step testing was +65 °C. The further temperature increasing was not permissible as further temperature growth led to melting of lens and package made of optical compound. The increments $\Delta I_1 = 25$ mA and $\Delta I_2 = 50$ mA, the stage duration was 24 h. Every i-stage was characterized by forward current I_{opi}. At the first stage of testing we used forward current $I_{op1} = 50$ mA.

Every stage of testing may be characterized by its number N_i and operating current I_{opi}. The relation of these values is represented by the following expressions:

$$N_i = \left(\frac{I_{opi} - I_{op1}}{\Delta I}\right) + 1$$
$$I_{opi} = \Delta I \cdot (N_i - 1) + I_{op1} \quad (1)$$