Investigation of radiation influence on LED

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Abstract. In this paper the investigation goal was to study the radiation effect (irradiation by fast electrons) on detectors, LEDs electro-physical parameters as they are widely used in space shuttles, satellites and airplanes on which space radiation influence. It was detected the critical value of irradiation for the irreversible changes in LED. The way for reducing characteristics degradation is suggested.

1. Introduction

High technical and economical performance of modern semiconductor sign indicators, detectors and light-emitting diodes (LEDs) make their usage one of the most promising areas in the visual display systems development. Using high efficiency InAlGaN Heterostructures (Het.) is an important milestone in the semiconductor devices development.

Investigation results that are discussed in current paper are relevant, due to necessity to improve the radiation hardness of devices designed to operate in extreme conditions, with increased lifetime.

The simulation methods, radiation process (RP) usage in the production of semiconductor devices (SD) and integrated circuits (IC) can effectively regulate the amplifier and pulse parameters of transistors (discrete and composed chip), LEDs quantum efficiency as well as eliminate the lightly controlled operation of the gold and platinum diffusion, to achieve new combinations of devices parameters (amplifier, efficiency, pulse, frequency), to study and improve their radiation resistance and stability [1-8].

SD parameters depend on many technological factors, it explains the large spread of finished products property values. RP is based on the effect of radiation centers formation in semiconductors irradiated by fast electrons or by other forms of ionizing radiation. Caused radiation centers, characterized by high stability in the operating temperatures ranges and electrical loads change electrical properties of semiconductor materials in various areas of the device structures and, accordingly, electric characteristics of semiconductor devices and integrated circuits. In the interaction, the electron energy is consumed mainly for the inelastic scattering on atoms, causing their ionization. The electron irradiation at low integrated flows creates mainly as primary defects the simple defects types with a uniform distribution in the volume of irradiated device.

Radiation process consists of the following operations:

- controlled irradiation of semiconductor structures or devices by fast electrons;
- annealing the irradiated semiconductor structures or devices.

The LED samples were irradiated by an electron flux with an energy from 4 to 5 MeV and doze upto 10^{15} e/cm^2 as the same average level in space. The minimum energy is determined by threshold

energy of shift (bias). It is allowed the irradiation with a higher electron flux density if the structures or devices temperature at the subsequent irradiation does not exceed the stabilizing treatment temperature.

Required integral electron flux for specific types of SD and ICs may be approximately selected by calculation or, by nomograms which are obtained experimentally. The nomograms are created based on the requirement to obtain a certain value of the controlled parameter, or a device parameters combination after irradiation operations and stabilizing treatment.

The irradiated sample annealing is used to stabilize the surface and bulk properties of the device structure and the optimum combination of device parameters after the irradiation and annealing operations. Stabilizing annealing may be performed immediately after the irradiation at increased temperatures or during subsequent processing operations. However, experience has shown that most effectively it is the carrying out separate operations annealing irradiated SD structures and IC under strictly controlled conditions. Irradiated structures on wafers or devices located in a heating chamber in which the temperature is set not less than 150 °C. For a particular device type the annealing conditions (temperature, time, environment) are determined by experimentation, based on the need for stable parameters and their optimal combination at the maximum allowed temperature.

For the stability improvement of the device parameters, the last RP irradiation is advisably carried out by a flux $6\cdot10^{14}$ cm^2, which is caused by an increase in the most stable of radiation centers, the probability of their creation increases with the concentration of vacancies.

For RP it is advisably apply linear electron accelerators with energies up to 8 MeV, due to their main advantages: the possibility of obtaining high electron flux power and current control over a wide range, relatively small size and a high reliability. Linear accelerator that was used in the experiment is a controlled pulse source of monoenergetic electrons with the energy - 5 MeV. Electrons appear due to emission in the electron source, then they are drawn into the injector that ejects electrons in accelerating tube of accelerator. Electron acceleration in the accelerating tube is under the influence of high-frequency field, synchronized in phase with the input moment of the electrons bunch into the accelerating tube. From the theory of free electron movement in the high frequency (HF) field, it follows that for sustainable progressive motion of the electron in the HF field it is necessary that the initial phase of the electron motion is multiple divisible by π. In this case, the free electron will have the energy E from the HF field. Since the free electron energy, increased (flight time of the accelerating gap is decreased), it is necessary to increase the next accelerating gap to maintain the free electron energy increment from the HF field. Practically the implementation of electrons resonance acceleration by the HF field linear accelerator is a diaphragmatic waveguide. Since from the injector into the waveguide the electron bunch with a different phase angle enters at the initial section of the acceleration the automatic selection of free electrons occurs, the phase of which is different from a predetermined equilibrium phases. Since the accelerating HF field has a maximum value along the waveguide axis for focusing the electrons it is used a longitudinal magnetic field causing electrons to move close to the centerline of the waveguide line to obtain the maximum accelerating effect.

Electromagnetic oscillations of a microwave range are produced by generator, power is supplied to the diaphragmatic waveguide. The generator operates in a pulsed mode, since the generator power should be significant for the creation of the necessary strength of the accelerating field. As a generator of microwave oscillations it is used powerful pulsed magnetrons and klystrons, the voltage to the generator is supplied by short pulses of up to 5 μs with a predetermined sending frequency, which is produced by a modulator formed on pulsed hydrogen thyratrons. At the same time from the modulator voltage is supplied to the injector, injecting electrons into the accelerating disk loaded waveguide.

Thermal processing of irradiated LEDs in order to stabilize their parameters for a given dose was carried out by isothermal annealing in a laboratory tube furnace. Temperature constancy in the work area is 5 ^{0}C. The specified temperature value is maintained automatically. Operating furnace chamber heating is a quartz tube fitted with external heating elements and the ceramic end caps.

2. The experimental procedure

The main LED characteristic is a I-V and efficiency. The main reasons for theoretical and experimental deviations are:

- the devices and material surfaces influence;
- generation and recombination of carriers in the depleted layer;
- tunneling of carriers between the states in the band gap;
- a high level of injection observed even at relatively low forward bias;
- the effect of sequential contact resistance.

The surface has an effect on p-n–junction mainly due to ionic charges on it or near it, which induces charges in the semiconductor. This leads to the formation of so-called surface channels or depleted surface layer. The presence of the channel region affects on the depleted p-n – junction surface and causes an increase in leakage currents. In the planar p-n– junctions the surface leakage currents are typically much less than a generation current in surface leakage region.

Actual experimental results in the general case can be described by the following expression:

$$I = \exp\left\{ \frac{e \cdot (U - I \cdot R_K)}{nkT} \right\},$$

(1)

where I – current, mA; e – electron charge, C; U – voltage, V; R_K– consistent contact resistance; n – nonideality factor; k– Boltzmann constant, J/K; T – temperature, K.

The product $I \cdot R_k$ is the voltage drop on the LED contacts. Nonideality factor takes into account the deviation of the experimental current-voltage characteristics from ideal linear (logarithmic scale) characteristics. At the predominance of the recombination current $n = 2$; at the predominance of the diffusion current $n = 1$. If both currents are comparable in magnitude, then the value of n is between 1 and 2.

The investigation was made by two irradiations and annealings to detects critical irradiation doze.

3. Results and discussion

It has been investigated the radiation influence on the blue and green LEDs electrical parameters: I-V, watt-voltage and spectral characteristics after irradiation (average doze according space influence) and after subsequent annealing as shown in Figure 1-3.
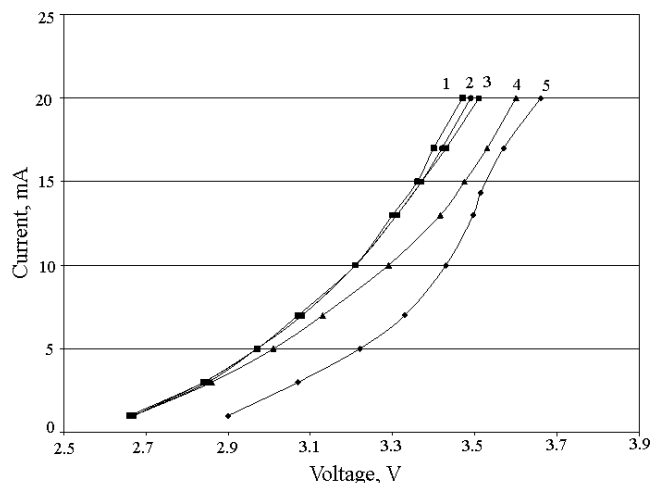

Figure 1. The typical I-V trend for blue and green LED: 5-initial, 4-after irradiation with doze 10 [14] cm[2], 3-after 1st annealing, 2-after irradiation with doze 6·10 [14] cm[2], 1-after 2nd annealing.
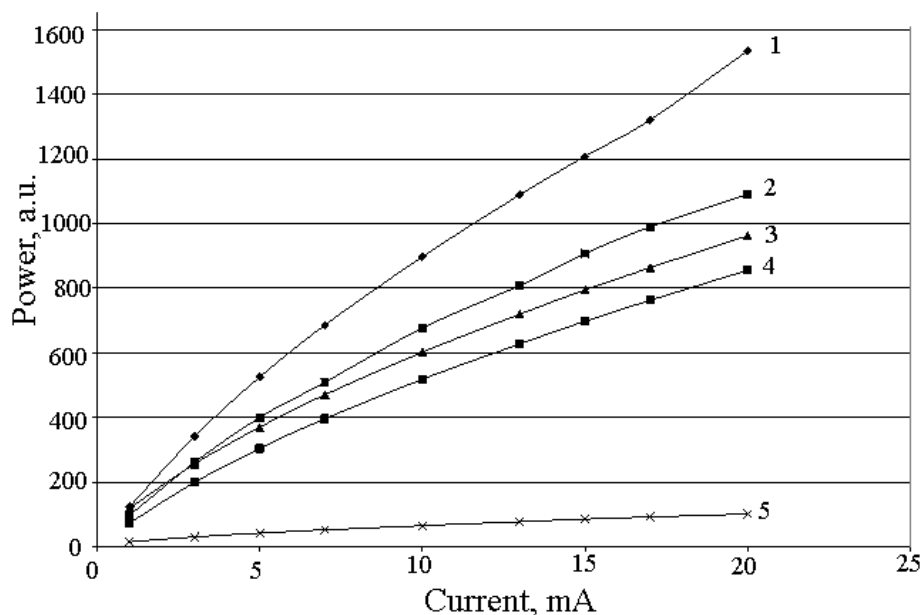
Figure 2. The typical trend for the watt-ampere blue and green LED characteristic:

1-initial, 2-after irradiation with doze 10 ^{14} cm^2, 3-after 1st annealing, 4-after irradiation with doze 6·10 ^{14} cm^2, 5-after 2nd annealing.
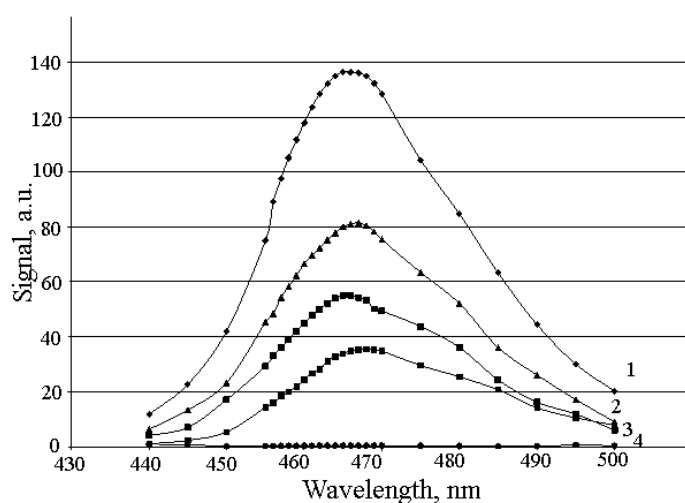

Figure 3. Spectral distribution vs wavelengths for the blue LED:

1-initial, 2-after irradiation with doze 10 ^{14} cm^2, 3-after 1st annealing, 3-after irradiation with doze 6·10 ^{14} cm^{2}g (no 5 curve as no effect was detected).

It was detected:

- after the first electron flux irradiation 10^{14} e / cm^2 it was occurred the characteristics degradation, the radiation power decreased;

- after annealing there was a slight recovery.

- after the second electron flux irradiation $6 \cdot 10^{14}$ e / cm^2 the power of radiation has decreased;
- after even the second annealing the characteristics recovery was unconvertible.

The performance characteristics degradation is a consequence of changes in the Het. composition and structure. Knocking out of the impurities from the interstitial sites or replacement of the gallium impurity atoms in the crystal lattice, as a result, leads to stress in lattice breaking impurity complexes.

"Red" shift to longer wavelengths is a consequence of the fact that the areas of low-atoms In comparison with the average value, creating a short-wavelength part of the radiation, are subject to destruction. The areas are like "burn" or In atoms are redistributed, since on the one hand through them high-density currents pass, on the other hand due to external irradiation influences (fields, irradiation influence (II)) and the induced by them effects. It appears more areas with high In atoms concentration and, consequently, the long-wavelength part of the electroluminescence spectrum increases. It may be also due to the piezoelectric effect (PE) and spontaneous polarization (SP) caused by the II, current or long running time. This effect may also be due to Stark and Stocks effects. The conclusions of some studies confirm this model. The significant decrease in the forward voltage at high current densities after II is well explained, because the elements with a reduced In atoms content have the greatest E_g, and consequently, the highest value U_f. However, an increase in the half-width of the spectral distribution is associated with the change in certain areas of the radiation parameters, it is possible to have the shorter waves than before the II, for example due to changes in the distribution of the intensity of the applied field and the higher density currents flow through this element. Figure 3 shows that the degree of change in the composition of the spectral distribution may depend on irradiation doze and it is associated with the occurrence of the resonance properties of SP effect.

The growth of long-wavelength components leads to the radiation efficiency of those parts of the structures that emit them, which however is not proportional to substantial degradation of sectors radiation with the central wavelengths and therefore the total integrated luminous flux decreases. After II the shunt effect appears as described above. However, different power characteristics changes may be due to a significant parameters mismatch of the crystal lattice of the Het. and the substrate.

Considered part of the model said that the SP is a major contributor to the "red" Stark energies shift in the GaN quantum well. Known effects associated with external electric fields (Bloch oscillations, Stark localization states, band-band tunneling), are significantly modified in the presence of internal polarization, and can occur even with a small number of ultra-thin layers of Het.

At high current densities, the difference in the behavior of the quantum efficiency with respect to the initial moment significantly increases. It is also due to the shunting effect of the described areas - the results of breakdown action of big potentials arising due to the PE. The current flow is already accompanied by a significantly greater proportion of non-radiative acts. However, the difference gradient decrease of the optical power between the Het. with a variety of substrates can be caused by a difference in the degree of mismatch periods of the substrate gratings and structures. This is clearly seen when considering the figures for the LED on sapphire and silicon substrates. Large drop values of optical power will meet the increasing mismatch lattices parameters. Mechanical II intensities this mismatch by defects formation caused by the difference in the mechanical parameters of materials with different lattice constants.

A marked reduction of optical power and voltage, respectively, at the same time II is seen in Figures 1-3. On variation in performance the changes of the applied external field and the high current density flowing through the Het. influence. It depends on irradiation doze, which in turn is connected to the resonance SP nature effect. The above part of the model pointed out that the PE field influence leads to a "red" shift of luminescence with respect to the E_g width of bulk material and the absorption edge, and a noticeable decrease in the oscillator strength. On the other hand it is likely that II activates the impurities in the AlGaInN Het.: donor oxygen which presents in the of $Al_xGa_{1-x}N$ layers and its activation amplifies the effect of DX-centers, as it can replace N_2 atoms in the lattice sites, which will create additional defects; it is probable the Mg-H_2 complexes disintegration, which will create additional parasitic resistance in the LED. Irradiation creates high-frequency piezoelectric field which

is superimposed on the static piezoelectric field and the SP, e.g. there is a combined effect. These phenomena could extra added for above results explanation.

4. Conclusions

It is determined the maximum unconvertible influenced by radiation electron flux $6 \cdot 10^{14}$ cm^{-2} with an energy of 5 MeV on LEDs. It leads to the characteristics degradation. It is shown that the resistance was increased performance degradation of I-V, watt-ampere and spectral characteristics. This degradation relates to the formation of defects and atoms redistribution in the Heterostructure, which could be due to the lattice mismatch of substrate and active region. Thermal annealing at 150 ^{0}C did not lead to the full samples recovery.

This could be solved by GaN substrates usage.

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