The thermal characteristics of superlattice structures based on AlGaInN solid solution

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Abstract. The blue light-emitting structures based on solid solutions of the system AlGaInN that contained superlattices $In_{0.9}Ga_{0.1}N/In_{0.99}Ga_{0.01}N$ and $Al_{0.15}Ga_{0.85}N/GaN$ were investigated, and its basic parameters and characteristics were defined. The main difference between the samples was an "upper blocking layer" that formed by AlGaN solid solutions with a different stoichiometric composition or as a superlattice. Spectral and thermal investigations of samples were conducted, and the temperatures of the active region were calculated. The optimal types of structures for different operation modes were offered.

1. Introduction

Improving of the white and blue light sources based on gallium nitride and its solid solutions is one of the key tasks of the semiconductor industry. Low emitting power, insufficient quantum efficiency and fast degradation of the structures at high operating currents still limit using of light emitting semiconductor devices as effective light sources.

Electroluminescence efficiency is a main characteristic of LEDs. One of the main reasons of its decreasing is a low quality of epitaxial heterostructures [1-4]. Effect of Auger-recombination is making a significant influence at high-power mode. In addition, a significant influence on the efficiency has self-heating processes in the emitting structure. It is actual to study these processes and to investigate of the influence of light emitting structure construction on the efficiency of luminescence. Superlattice (SL) may improve the quality of the structure and enhance the efficiency of blocking layer above the active region. In the paper the impact of SL to self-heating and the efficiency of light-emitting structures was examined.

2. The samples

In this work were investigated four types of samples of structures based on solid solutions of AlGaInN [5,6] system and disposed on sapphire substrates of diameter 3 " (figure 1). These structures were created by the method of metalorganic vapour phase epitaxy (MOCVD). Samples in cross-section is a «sandwich structure» with the quantum well and superlattices.

An important feature of investigated structures was using superlattices based on solid solutions AlGaN or InGaN. First SL was between bottom n-layer and active layer. It consisted of 15 pairs $In_{0,9}Ga_{0,1}N/In_{0,99}Ga_{0,01}N$ (width of every layer – 1 nm). This SL was intended to reduce the concentration of defects in the active layer (AL). AL comprised single quantum well (SQW) $In_{0,15}Ga_{0,75}N$. It width was 2.5 nm. The barrier layer i-GaN blocked the process of diffusion between p-emitter and AL.

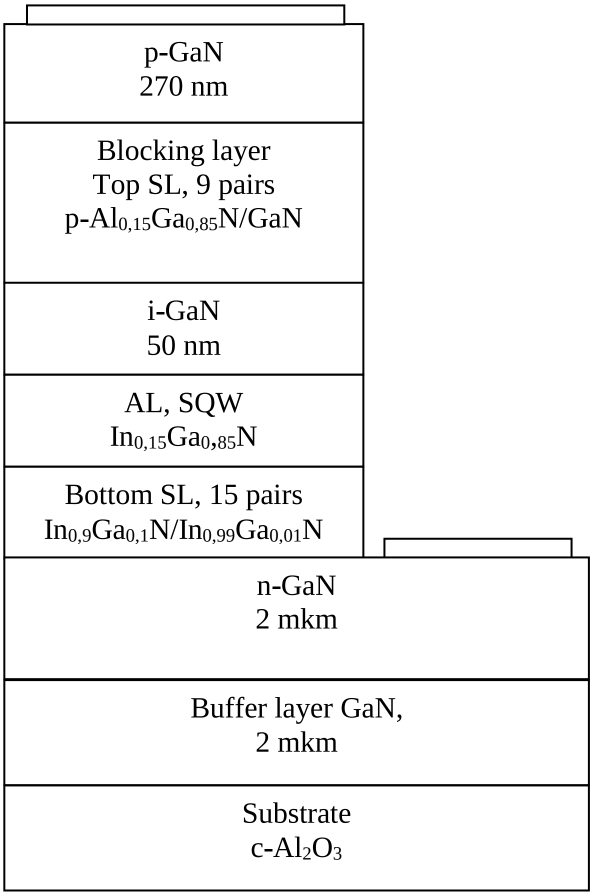

Figure 1. Light-emitting structures 114, based on solid solutions AlGaN or InGaN

Main attention was given for exploring the influence of upper blocking layer structure on the parameters of light emitting crystals, especially on the process of current distribution and thermal effects connected with it. First type of samples (114) contained blocking layer with a SL based on 9 pairs of p-$Al_{0.15}Ga_{0.85}N$/GaN with a thickness of every layer 1.5 nm. Samples with more simple structure of blocking layer had explored to determine all possible advantages of superlattice. Two types of crystals contained a simpler layer, based on a solid solution of aluminium gallium nitride: p-$Al_{0.15}Ga_{0.85}N$ (115) or p-$Al_{0.1}Ga_{0.9}N$ (116). In the last case, the blocking layer didn't contain AlN and was grown from a uniform p-GaN (117). In all samples, the thickness of the blocking layer was 27 nm and the concentration of the dopant was approx. $3 \cdot 10^{17}$ $см^{-3}$. A layer of p-GaN with a thickness of 270 nm completed the structure of all samples.

3. Experiment

The investigations were conducted using the developed hardware and software system. It includes thermostats, integrating spheres, quick scanning spectrometers produced by OceanOptics company and other measuring equipment [7-9]. Non-contact determination of the active layer temperature of the light-emitting structures is an important feature of the system. The experiment was conducted in accordance with international standard CIE 127:2007. The installation includes a probe station. This allowed investigating the temperature characteristics of the crystals in the unseparated substrates.

It was shown that an increase of the direct current leads to growth of the AL temperature to a value of 100 °C and above. This increasing was determined by the processes of charge transport and a change in the probability of quantum transitions in the structure. The relation between the efficiency of luminescence and thermal effects in the structures was studied. The figure 2 shows the luminescence spectra of the LED structure 116 at different currents. It can be seen that the shift of the maximum emission is a superposition of short-wave driving in connection with the Stark effect and temperature shift to longer wavelengths, which begins to dominate at a current rise above 150 mA. On a set of spectral characteristics was made a comparison between the sample spectral characteristics (Figure 3). The relative performance characteristics and the AL temperature are shown in Figure 4.

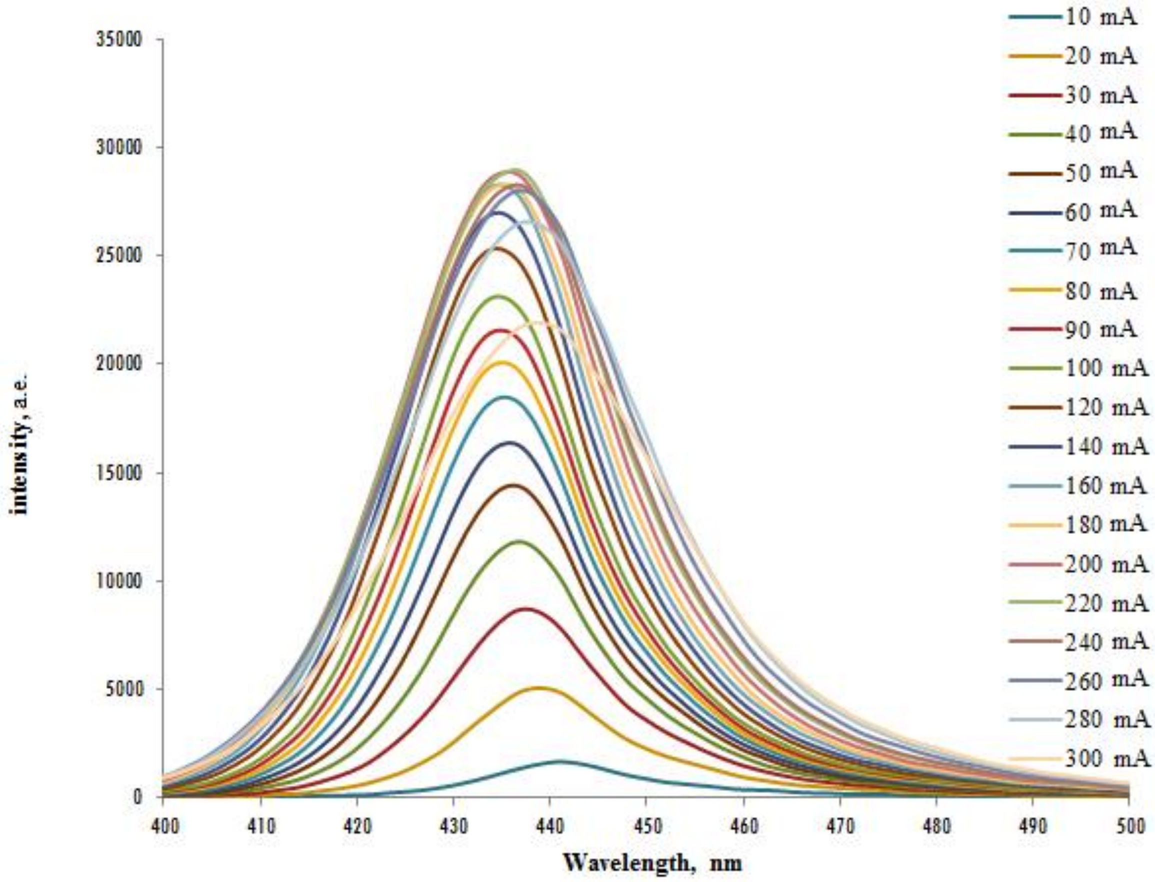

Figure 2. The luminescence spectra of the structure 116 at different currents

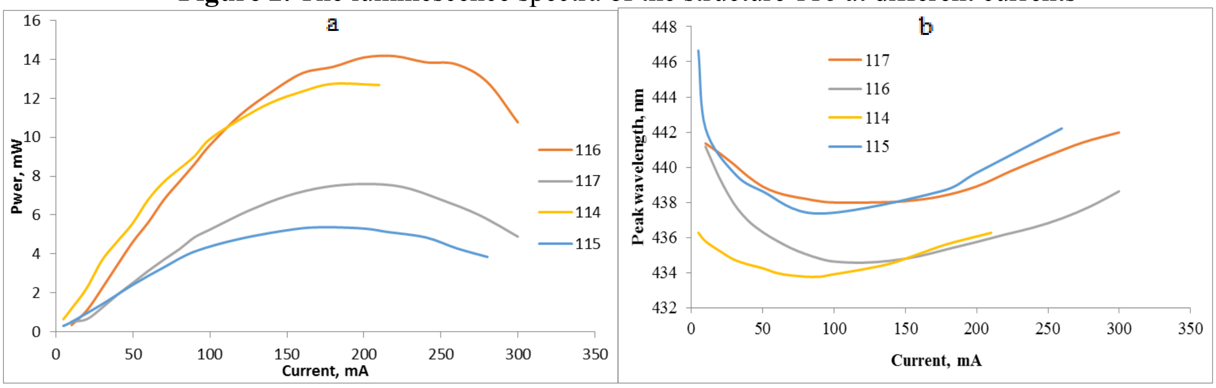

Figure 3. Power-current characteristics (a) and peak wavelength-current characteristics (b)

It was shown that the use of the SL in the blocking layer allows to provide the highest efficiency at low currents, due to improved barrier properties of the layer. The efficiency and power of all samples decreased when the current increased due to the heating of the structures and the increasing intensity of the Auger recombination (figures 3b and 4b).It is found that this reduction in efficiency for samples with 10 % AlN in the BL (116) is slower than for samples with SL (114). This leads to a smooth increase in the temperature of the active region of such samples (fig. 4b), so the use of such structures at high operating currents is preferable.

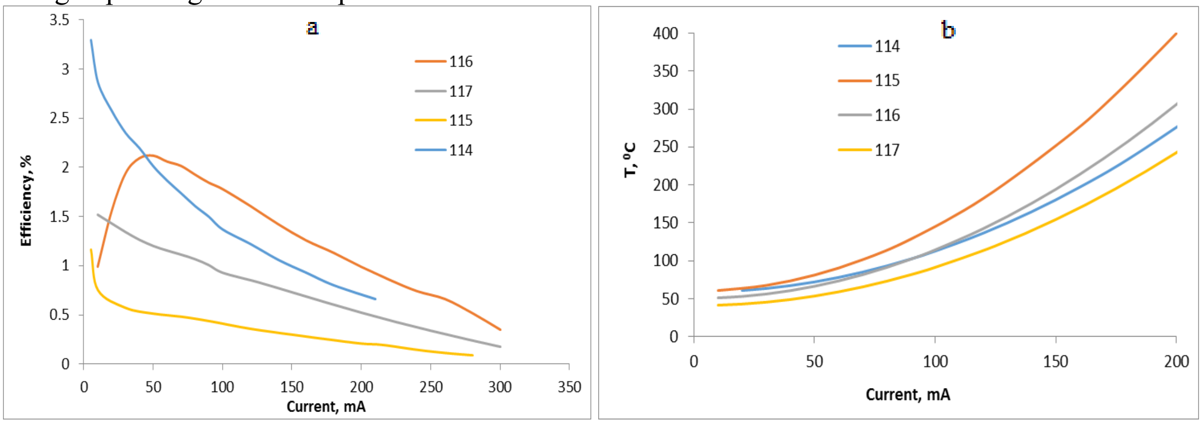

Figure 4. Efficiency characteristics (a) and temperature dependence of the currents (b)

This was associated with a sharp increase in the intensity of Auger recombination processes in the structures with SL. In this paper, the relation between the Auger recombination effects and thermal properties of structures is examined, as well as its effect on the power efficiency of the samples. Preliminary estimates show that the analysis of these effects allows for a quick assessment of the quality of structures, perspective for introduction in industrial enterprises.

4. Conclusions

The study of AlGaInN light-emitting structures containing superlattice $In_{0.9}Ga_{0.1}N$ / $In_{0.99}Ga_{0.01}N$ and $Al_{0.15}Ga_{0.85}N$ / GaN, was conducted, and its main parameters and characteristics were defined. It was shown that the highest efficiency at low currents was observed in the structures having a superlattice in the blocking layer. At large currents the efficiency was decreased for all samples. Nevertheless this decrease in efficiency was slower for samples with 10 % of AlN in the blocking layer than for samples with SL. This leads to a smooth increase in the temperature of the active region of such samples,. This is associated with a sharp increase in the intensity of Auger recombination processes in the structures with SL. Thus light-emitting structures containing $Al_{0.15}Ga_{0.85}N$ / GaN superlattice is preferable at low operating currents. At low operating currents structures with 10 % of AlN in the blocking layer are more preferable.

Acknowledgments

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