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Study of power limitation of AlGaInN LEDs in pulse regime at high current

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Abstract. LEDs operating under high pulsed current are of a great interest for different applications, in particular, for VLC (LiFi) systems and laser pumping. Current dependences of the efficiency and emission spectra as well as the rise and fall times of high-power blue LEDs were investigated under extremely high pulse current density up to 7 kA/cm² and pulse duration from 100 ns to 3 μ s. Analysis of the pulse behaviour of the LEDs reveals that the main droop in the efficiency and change in spectra occur up to the current densities ~ 1 kA/cm² and seems to be non-thermal.

1. Introduction

The scope of application of light-emitting diodes (LEDs) keeps expanding. The study of the operation of LEDs in pulse mode at high excitation levels is of a great interest because it could allow one to establish the mechanisms behind injection and recombination and to clarify the reasons limiting the energy capabilities of devices [1-4]. In this paper we studied vertically designed LED chip in the short-pulse regime $\tau = 0.1 \dots 3 \mu s$ at ultrahigh operating currents – up to 70 A (j ~ 7 kA / cm²).

2. Experimental setup

2.1. Test sample

For our study, we selected commercial non-casted Enhanced Vertical LED chip EV-B40A (peak emission wavelength $\lambda_{peak} = 460$ nm) with the emission area of $1100 \times 1100 \ \mu\text{m}^2$ produced by SemiLEDs [5]. The chip had a simple contact geometry shown on figure 1. For characterization, the chip was soldered on silicon submount, which was then mounted on bulky heat sinks.

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Figure 1. Schematic design of the EV-B40A chip.

2.2. Light-current characteristics of LEDs

The optical parameters of the devices under investigation were measured in pulse mode. We used an Agilent 8114A pulse generator in conjunction with a PicoLAS LDP-V 80-100 V3.3 external amplifier to ensure the predetermined pulse regime. The pulse width and duty cycle were monitored by a Tektronix TDS3044B oscilloscope. The light pulse was measured by a Si-based THORLABS DET02AFC/M photo detector. Spectral characteristics were recorded by an OL 770-LED High-speed LED Test and Measurement System [6]. The duty cycle was chosen to avoid self-heating at f = 50 Hz. The pulse duration was varied in the range 100 - 3000 ns.

2.3. Measuring of near-field of electroluminescence (emission intensity distribution)

Near-field (NF) distributions of electroluminescence (EL) intensity were monitored by Mitutoyo optical microscope with Canon camera (12 Mpxl CMOS photo-sensitive matrix). The minimum and maximum fields of view of the optical system were $536 \times 357 \ \mu\text{m}^2$ and $5362 \times 3520 \ \mu\text{m}^2$, respectively. The best spatial resolution was 0.5 μ m. The optical system collected the light within the 15° cone around the normal direction. NF emission spectrum distributions were monitored by Mitutoyo optical microscope in conjunction with Avantes AvaSpec-2048 spectrometer (the spatial resolution was 25 μ m).

2.4. IR thermal imaging

IR thermal imaging was used to determine the surface temperature of the chip. It allows us to measure the temperature directly and thereby to obtain more detailed temperature data. The IR thermal radiation in the spectral range of $2.5-3.0 \mu m$ was mapped by a specially designed IR microscope [7].

3. Results and discussion

The measured output optical power dependence on current of *AlGaInN* LEDs showed a strong fall in the external quantum efficiency (EQE) over a current density increase up to 7 kA/cm^2 (figure 2) at pulse duration τ =100 ns. An especially sharp drop occurs in the range of currents I of several amperes (J<1 kA/cm2). The temperature of LEDs was controlled by the spectral analysis and the IR imaging. No self-heating effect was observed.

NF of EL distribution over the chip area at the current of I = 70 A and τ = 100 ns is shown in figure 3 as a color chart. There is a remarkable difference in EL values near the edge of the n-contact and in the middle between the contacts at the operating current I=70 A.

The current crowding reduces an effective area of LED chip. As a result, EQE decreases with current density (efficiency droop) stronger than theory predicts, for example, the ABC-model. Furthermore, the localization of current can lead to the change in the thermal characteristics of LEDs.

Figure 4 shows IR microphotographs (IR radiation distribution over the area) for the LED chip at I=70 A. The small color contrast around the perimeter of the chip is due to the different emissivity of materials included in the chip (semiconductor, metal contacts). To convert the value of IR intensity to the temperature we used pre-calibration data. In our case, there is a uniform distribution of the IR radiation intensity, and therefore, there is no temperature gradient when operating in a given pulse mode.

The spectral analysis of EL (figure 5) in cross-section AA (insert to figure 2) showed only a blue shift effect. No change in a slope of the high-energy shoulder of spectrum was observed which also indicates a lack of self-heating.







Figure 4. IR image of LED chip at I = 70 A.

Figure 3. 2D NF of EL distribution at I=70 A.

600

Length, µm

800

1000

400

ntensity, bit



Figure 5. Normalized LED spectra in crosssection A: (near n-contact (1) and in the middle between the contacts (2) at a I=70 A.

4. Conclusions

High-power AlInGaN blue LED chip of «vertical» design have been studied by advanced experimental techniques including high-resolution mapping of EL and IR radiation (thermal imaging)

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in short pulse regime at high currents. EL intensity, spectral and temperature distributions over the LED area were studied and analyzed.

A strong drop in EQE over a current increase is compounded by the current crowding effect. Thus, it is incorrect to use the average current density over the chip area in theoretical simulation.

The results of the study of the IR radiation showed a uniform temperature distribution and lack of noticeable self-heating at high-pulse current mode (I=70 A, τ =100 ns f=50 Hz). The latter is confirmed by the only a blue shift effect without any change in a slope of the high-energy shoulder of the spectra with an increase of the current.

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