Chromaticity coordinates temperature dependence for blue laser diodes for solid state laser lighting

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Abstract. Colour characteristic temperature dependence of such as X- and Y-coordinates (CIE 1931) for high power blue laser diode was investigated. It was shown, that thermal stability of colour characteristic of high power blue laser diode allows to create solid state lighting.

1. Introduction
Every year the lighting market based on “white” LEDs is growing dynamically. This is due to several reasons: high lifetime, compactness, usage simplicity, high efficiency, low power consumption [1]. However, despite their advantages, blue LEDs that are used as optical radiation sources for exciting the phosphor luminescence, based on the yttrium aluminum garnet doped with cerium (YAG:Ce³⁺), have several fundamental drawbacks: internal quantum efficiency drop at high current densities, that with the total internal reflection effect, reduce the external quantum efficiency[2]. Laser diodes (LD), as sources of optical radiation, do not have such disadvantages as described above, as compared with LEDs [3, 4].

Previously, it was shown that the color characteristics of solid state laser lighting systems can correspond to the color characteristics of an absolutely black body [5]. From the point of view of laser lighting systems operation, the color characteristics stability as a function of temperature is a great practical interest.

The goal of current work was to investigate the color characteristics temperature dependence of the blue high-power laser diodes versus temperature.

2. Experiment
In this investigation Nichia NDB7A75 LD was used as laser light source. LD was fixed on copper heat sink which in turn was mounted on thermal-electro cooler (TEC). LD spectral characteristics were measured in temperature range 15-30 °C by S-150HR spectrometer. This spectrometer has a very high resolving power (up to ± 0.01 nm).

3. Result and Discussion
In Fig.1a the dependence of the laser diodes spectral characteristics at a fixed temperature vs the pump current are shown. In Fig. 1b the dependence of emission spectral characteristics at fixed optical
radiation power versus temperature are shown. Then, calculations, based on these spectral characteristics have been provided.

Figure 1. Spectral characteristics LD : a) at a fixed temperature (20°C) vs the forward current; b) fixed optical radiation power (1500mW) vs temperature

In the Fig. 2 X- and Y- chromaticity coordinate (CIE 1931) dependence versus output power at fixed temperature are shown.

Figure 2. CIE 1931 X- and Y- chromaticity coordinate dependence versus output power at fixed temperature

It can be seen that increasing temperature in range 10-30 °C led to a decrease X- and increase Y-coordinates. For curve corresponding to 10 °C, 15 °C and 30 °C angle of inclination changes insignificantly. For curve corresponding to 20 °C and 25 °C slight deviation of inclination angle was observed. This can be explained by a LD spectrum fluctuation due to indium fluctuation in quantum wells [6]. The difference between the X-coordinate values at 10 °C and 30 °C does not exceed 0.0015, the difference between the Y-coordinate values at 10 °C and 30 °C does not exceed 0.002. The values for the color coordinates change versus the temperature and the output power of the LD are in the range of the tolerance values for the color coordinates determination (less than 0.01) for the light sources in accordance with CIE1931. Based on this, it can be concluded that the temperature change has a slight effect on the solid state laser lighting color parameters.
Further, we investigated the wavelength deviation dependence at the maximum of the LD emission spectrum ($\lambda_{\text{max}}$) and the LD dominant wavelength ($\lambda_d$) versus the temperature at different output optical power. The results are shown in Fig. 3.

![Figure 3](image)

**Figure 3.** Maximum ($\lambda_{\text{max}}$) and dominant ($\lambda_d$) wavelength dependence versus output power LD

It can be seen that difference between $\lambda_{\text{max}}$ and $\lambda_d$ increases with increasing LD output power. It can be explained by spectrum line width rise. Difference between $\lambda_{\text{max}}$ and $\lambda_d$ in output power range 20 – 1500 mW does not exceed 1 nm at difference temperatures. Figure 4 shows the area in the CIE1931 color space for LD at 1000 mW and 1500 mW.

![Figure 4](image)

**Figure 4.** LD color coordinates location versus temperature in the CIE1931 at fixed output power: a) 1000 mW; b) 1500 mW

The red and blue lines connect the LD color coordinates and the phosphor based on YAG:Ce$^{3+}$. The color temperature value for this source is CCT = 4500 K, the black dots on the border of the color space indicate the area that corresponds to the deviation from the CCT by 30 K. It can be seen in the figure that the LD color coordinates lie entirely in this region, which indicates a high stability of the color temperature.

4. **Conclusion**
LD color coordinates dependences at different output optical power values versus temperature are investigated. It is shown that at the temperature change, the LD color coordinates change insignificantly, the deviations of the X- and Y- color coordinates according to CIE1931 do not exceed 0.01. The dependence of the dominant wavelength and the wavelength at the maximum of the laser
radiation spectrum at the temperature versus different values of the output optical power was investigated. It is shown that the dominant wavelength and the wavelength at the maximum of the emission spectrum vary slightly with temperature. It is detected that the difference in values between $\lambda_{\text{max}}$ and $\lambda_{d}$ is negligible, therefore, only $\lambda_{\text{max}}$ can be used to estimate the color parameters of laser radiation systems. Changing the color coordinates at different temperatures leads to a slight deviation of the CCT, not more than 30 K. It can be concluded that high power blue LDs provide stable colorimetric characteristics such as X- and Y- coordinates (CIE 1931) and CCT. Blue LD has a promising future as a light source for solid state lighting creation.

References

[1] Jy Bhardwaj, John M. Cesaratto, Isaac H. Wildeson, Henry Choy, Ashish Tandon, 2017 Phys. Status Solidi A, 2 1600826
[2] Cantore M, Pfaff N, Farrell R M, Speck James S, Nakamura S, Den Baars S P 2016 Optics Express 24(2) A215
[3] Daniel Feezell, Shuji Nakamura 2018 Comptes Rendus Physique 19(1–2) 1–84
[4] Chelny A 2017 Semiconductors lasers and system 83
[5] Akhmerov Y L 2017 Semiconductors lasers and system 88
[6] Chichibu S, Nakamura S 1996 Appl. Phys. Lett. 69 4188