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# TEMPERATURE STABILITY OF COLORED LED ELEMENTS

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**Abstract.** Temperature stability of the optical power output of colored (blue-red) light emitting diode (LED) elements is considered. It is shown that LEDs based on blue 455 nm semiconductor chips have the best thermal stability, which is expressed in just 4 % of optical power losses with LED board temperature increasing from 25 °C up to 50 °C. The value of optical power losses for red chips emitting at 660 nm and 730 nm were 7 % and 11 %, respectively, while devices based on 455 nm blue chips and red nitride phosphors with 2 % and 8 % phosphor concentration showed losses of 4 % and 8 %, respectively. Wall plug efficiency of the studied samples demonstrated a similar trend with the temperature increasing as the optical power did.

## 1. Introduction

The progress in the efficiency that light-emitting diodes (LEDs) have been demonstrating in the past decade has sparkled the development of LED-based technologies for various industrial applications. In particular, LED-based polychromatic emitters intended for use in horticulture are currently experiencing a sort of 'revival'. This technology has been around for a number of years, but low efficiency of the previous generations of LEDs did not allow for using them in commercial greenhouse applications. On the other hand, there is a great demand in a lighting technology that would significantly reduce the consumption of electricity for greenhouse lighting while maintaining or even improving the value of the crop [1–6]. Energy-efficient LED-based devices of today seem to meet this need perfectly.

Greenhouse LED-based emitters typically employ LED chips that emit monochromatic light that match the absorbance peaks of important plant pigments, such as the red and blue peaks of leaf photosynthetic action spectra. The disadvantage of such devices is the necessity to provide different circuits for the current supply for the blue and red chips (typically based on (Al, In, Ga)N and (Al, Ga, In)P semiconductor systems, respectively), and different temperature stability of the different chips [7, 8]. It is known that thermal losses of optical power in LEDs are generally associated with the processes of non-radiative recombination (via deep levels and/or at the surface), and carrier loss over heterostructure barriers. Among chips of various colors, the blue ones typically demonstrate the best thermal stability as, among other factors, they possess the deepest quantum wells that provide the strongest carrier confinement [7]. The recent results indicate that luminous flux decay of the LEDs with the temperature increasing is indeed dependent on the chip material used [8], and not so much on the thermal resistance of the chips, which, in principle, can be adjusted. This makes it really difficult to match temperature stability of chips made of different materials, and makes one search for other solutions. 'Phosphor' solutions, which rely on a single kind of chips for the 'basic' color (typically, blue) and chemical phosphors for producing other colors (e.g., red) are becoming of interest in this respect. Phosphors, however, are also known to suffer from thermal effects [9–11] even though their nature is different: two major mechanisms that are believed to be responsible for the thermal quenching in phosphors are the Stokes shift and photoionization [12, 13]. The question of comparative temperature stability of LED elements based on solely chips and chip-and-phosphor, therefore, requires investigation. The aim of the present paper is to compare the changes in characteristics that occur with increasing the temperature of greenhouse LED elements based on blue, red and far-red LED chips, and blue chips and red phosphor.

## 2. Experimental

For the experiments, chosen were red and far-red LED chips with peak emission wavelength $\lambda$ of 660 nm and 730 nm, respectively, blue chip with $\lambda = 455$ nm and a red nitride phosphor with $\lambda = 670$ nm. Nitride phosphors are playing an increasingly important role in producing highly efficient and reliable white LEDs, due to their useful emission colors, high quantum efficiency, and high chemical/thermal stability [12]. The high quality of red light and good light conversion efficiency that they provide when excited by blue semiconductor chips make them excellent candidates for the sources of red and far-red light in greenhouse lighting. The choice of the red and far-red chips used in this work was motivated by the fact that the combination of these chips gives one an opportunity to match the spectrum of the final device to that of the device with the red phosphor.

For preparing the samples with LED chips, the chips of all three kinds (455 nm, 660 nm, and 730 nm) were placed with an adhesive on one plastic leaded chip board with a built-in metal radiator. After thermal ultrasonic welding the chips were covered with transparent stabilized silicone two-component polymer using dispensing technique. Then thermal drying has been done and the samples were ready for the measurements.

The samples with the phosphor were based on the same blue chips with $\lambda = 455$ nm and red phosphor with concentration of 2 % and 8 %. The phosphor powder was added to the same polymer as was used for 'chips only' LED elements, and the same kind of board was used for making the final devices.

To obtain a reliable result, 50 samples of each kind were prepared.

The electrical and optical characteristics of the samples were measured at the nominal DC current of 350 mA. The heating of the samples occurred naturally under flowing current. A thermocouple was placed at the back side of the board radiator to register temperature values.

The measuring system consisted of the spectroradiometer ORB Optronix SP-75 allowing for spectral measurements in 250–1000 nm range, 50 cm spherical integrator Gamma Scientific, power source 2601A Keithley and program pack Spectral Suite 3.0 for the registration of the measured optical and electrical values. The temperature was registered manually using Fluke 179 Measurer.

The obtained values were averaged by the number of the samples.

## 3. Analysis of the characteristics

Figure 1 shows the spectra of the fabricated devices. As can be seen, spectra of LEDs with the chips emitting at 660 and 730 nm correspond to the spectra of LEDs with the red nitride phosphor.

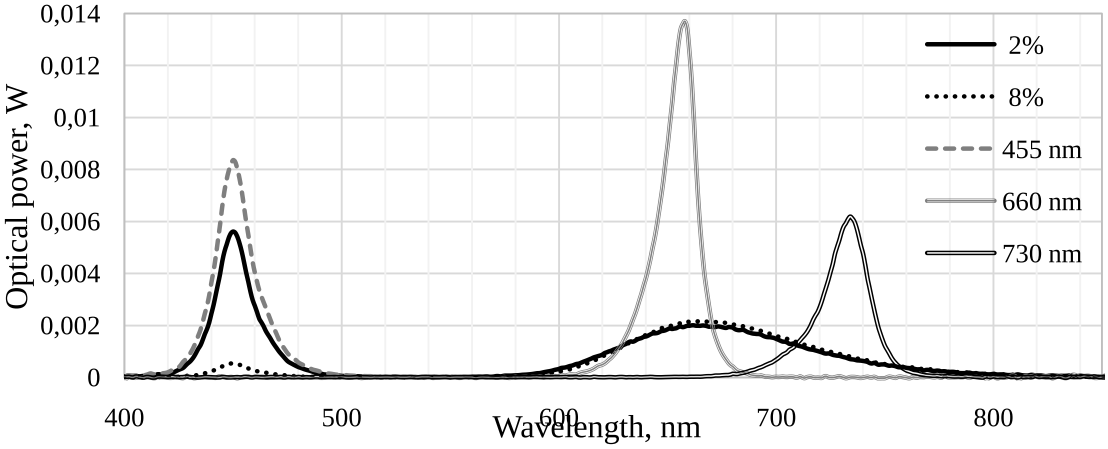


**Fig. 1.** Spectra of samples based on the blue chip and the phosphor at concentration of the latter of 2 and 8 %, and spectra of samples based on LED chips with peak emission wavelength equaling 455 nm, 660 nm, and 730 nm.

Figure 2 shows the dependences of the relative optical power of the devices on the board temperature. Since the presence of the phosphor influences the device operating temperature, the latter has smaller values in the 'chips only' samples and in that based on chip and phosphor with 2 % phosphor concentration. For these samples, before temperature saturation we could reach only 55 °C for chips emitting at 455 nm and 730 nm, while samples with phosphor concentration of 8 % got heated up to 65 °C.

Thermal stability of the samples based on blue chips appeared to be the best among all the considered samples. Only 4 % of optical power was lost when the board temperature rose up to 50 °C. Optical power stability of red (660 nm and 730 nm) chips was weaker: decrease of the optical power measured as the temperature increased from 25 °C up to 50 °C equaled 7 % and 11 %, respectively.

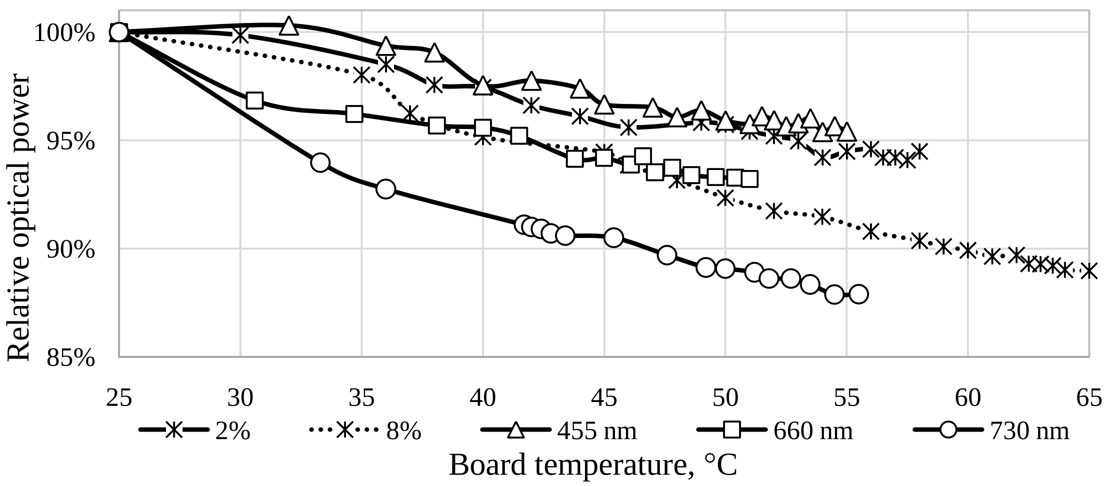


**Fig. 2.** The dependences of the relative optical power on the board temperature for samples containing phosphor with concentration 2 % and 8 %, and for the LED chips with peak emission wavelengths equaling 455 nm, 660 nm, and 730 nm.

Thermal stability of the optical power of the phosphor-containing samples at low concentration of luminescent particles was just a little smaller than that of the blue chips due to insignificant effect of the low thermal stability of the phosphor on the stability of the whole system. However, the decrease of the optical power of the samples with 8 % phosphor concentration at 50 °C amounted to 8 %. This is an expected effect as the high phosphor concentration always increases the thermal quenching, due to the enhanced Stokes shift [12].

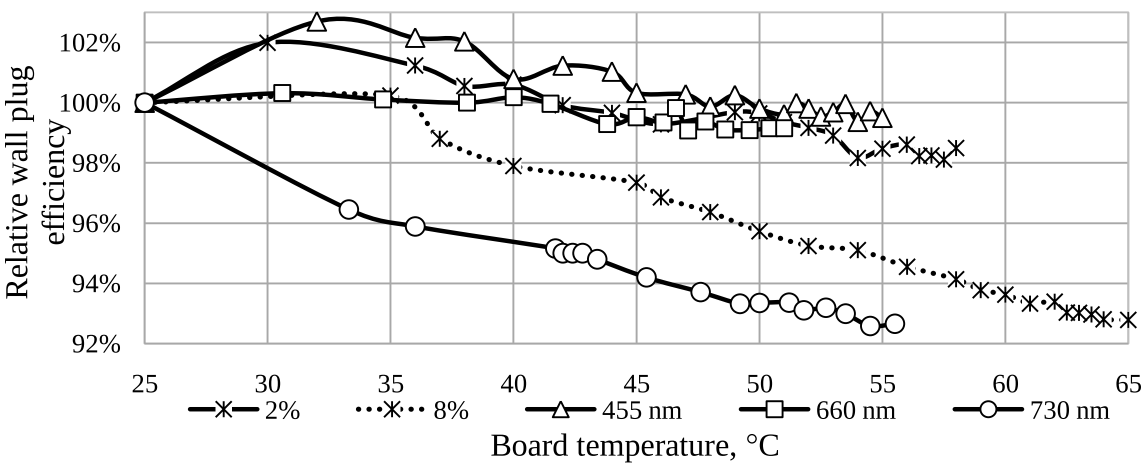


**Fig. 3.** Relative wall plug efficiency vs. board temperature for the samples containing phosphor with the concentration 2 % and 8 % and for the LED chips with peak emission wavelengths equaling 455 nm, 660 nm, and 730 nm.

Temperature dependence of the Wall Plug Efficiency (WPE) calculated as WPE = 100·($P_{opt}$ /$P_{el}$), where $P_{opt}$ is the optical power, and $P_{el}$ is the electrical power, had a general tendency similar to that of the optical power, which evidenced negligible changes in electrical power consumption as compared with the changes in the optical power. The relative changes of the WPE are shown in Fig. 3.

The results of the study show that it is indeed difficult to match the temperature stability of chips based on different semiconductor systems. The development of LED devices employing different monochromatic chips is still hindered by weak thermal stability of LED elements for the long wavelength part of the spectrum, as they are based on relatively narrow-gap semiconductors, which suffer from non-radiative recombination and carrier losses in heterostructure barriers. The thermal stability of the optical power of LED elements employing blue chip and red nitride phosphor even at relatively high phosphor concentration (8 % losses) still better than that observed for far-red chips (11 % losses). This shows that solutions employing phosphor-based color conversion are indeed promising for applications where colored LEDs are required and temperature stability is important.

## 4. Conclusions

For the first time, a direct experimental comparison of the temperature stability of colored (blue-red) LED elements based on chips only and chip-and-phosphor has been made. Decrease of the optical power and wall plug efficiency with board temperature increasing with the DC current flow has been considered in samples with blue chips emitting at the wavelength $\lambda$ = 455 nm, red ones with $\lambda$ = 660 nm and $\lambda$ = 730 nm, and LED elements with blue chips with $\lambda$ = 455 nm and red nitride phosphor with $\lambda$ = 670 nm. Thermal stability of the samples based on blue chips appeared to be the best among the considered samples. For them, only 4 % of optical power was lost when board temperature rose up to 50 °C, while for red (660 nm) and far-red (730 nm) LEDs the losses were 7 % and 11 %, respectively. Thermal stability of the optical power of phosphor-containing samples at low concentration of luminescent particles was a little smaller than that of blue LEDs due to insignificant effect of low thermal stability of the phosphor on the system stability. However, the decrease of optical power of the samples with 8 % phosphor concentration at 50 °C amounted to 8 %. WPE dependences have shown the same tendencies as the optical power. In general, the obtained results showed that 'phosphor-based' solutions are indeed promising for applications where colored LEDs are required and temperature stability is important, such as, e.g., greenhouse lighting.

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