KINETICS OF LEDS WHITE LIGHTING UNDER PULSE POWER SUPPLY

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Abstract: The paper presents the results of the study of energy and dynamic characteristics of white glow LEDs FYL-3014 and ARPL-1W when powered by U-shaped pulses. Based on the obtained oscillograms, it is established that the increase and decrease of the luminous flux is described by an exponential dependence, from which the constants of the relaxation time are determined. As the frequency of the pulsed power supply increases, the time constant of increase and decrease of the luminous flux decreases. Based on the analysis of the parameters of the light flux LEDs kinetics and its behavior with a change in the frequency of the pulse supply and the amplitude of the pulses, it is shown that one-component phosphor YAG:Ce is used. The most energetically favorable frequency range of pulsed power supply FYL-3014 and ARPL-1W of white glow is from 1 to 100 kHz.

Keywords: *LED, pulse-width modulation, energy efficiency, attenuation coefficient.*

1.Introduction.

Pulse power supply of LED light sources (LED) with pulse-width modulation has become the most common in lighting systems. It allows to use modern determination of the optimal pulse frequency is based on the analysis of the LEDs glow kinetics. Unfortunately, this problem is studied insufficiently, so the task was to conduct such studies for white glow LEDs.

This work is devoted to experimental studies of the kinetics of white glow LEDs based on InGaN-GaN structures (with a color temperature of 3000 °K and 6000 °K), which is a continuation of the study of transients in an electric circuit with commercially available LEDs FYL-3014 and ARPL-1W of 1 W and 3 W when powered by U-shaped pulses with latitude modulation [1-3].

2.Experimental installation

Measurements of spectral and dynamic LED characteristics were performed on an experimental installation, the block diagram of which is shown in Fig.1.

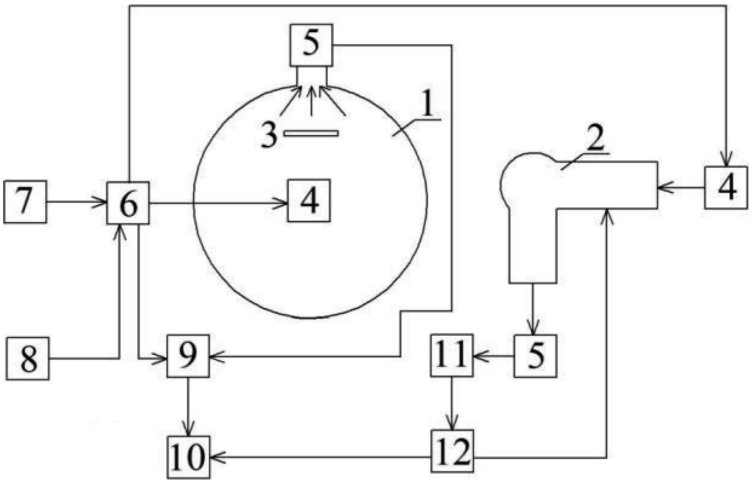

Fig.1. Block diagram of the research installation: 1 - integrated photometer; 2 - monochromator UM-2; 3 - screen; 4 - research light source; 5 - photodetector; 6 - switching device; 7 - adjustable voltage source SW3010D; 8 - SIGLENT SDG 1050 generator; 9 - SEA C8-22M / 1 oscilloscope; 10 - personal computer; 11- converter current - voltage; 12 - unit for processing of input signals and controlling the operation of the monochromator UM-2.

To study the energy characteristics, the light source (4) was placed in an integrated photometer (1). The electrical signal from the photodetector (5) was transmitted to the digital oscilloscope SEA C8-22M / 1 (9). An adjustable voltage source SW3010D (7), an SDG signal generator 1050 (8) and an electronic switch (6), which allowed switching current up to 10 A and voltage up to 100 V, were used to provide switching power of the LEDs. It allowed to supply light sources both with direct current and in pulse mode with a pulse frequency of up to 1 MHz with different fill factors. The current and the voltage, the amplitude and the pulse duration were monitored using a SEA C8-22M / 1 digital oscilloscope. Processing and storage of measurement results were performed using a personal computer.

UM-2 monochromator was used to study the spectral distribution of LEDs and to isolate the individual parts of the spectrum. The light pulse was measured by a photodetector (5), FEU-85 photoelectron multiplier (PhEM). The signal from the PhEM was fed to the operational amplifier (11), which was operated in the mode of the converter current - voltage. The operation of the monochromator was performed using ARDUINO NANO (12).

3.Research results and their discussion

Before proceeding to the study of lighting LED characteristics, measurements of its electrical parameters during switching power supply were carried out. Measurements were performed for two types of white light LEDs FYL-3014 and ARPL-1W. 1W LEDs were powered by the SIGLENT SDG 1050 generator, and an electronic key was additionally used to power the 3W LEDs [1].

Figure 2 shows the oscillograms of current and voltage pulses on the rising and falling edges, in an electric circuit with the studied LEDs. The oscillating nature of the transient process indicates the presence of reactive elements, contained in the structure of the LED, in the electrical circuit. The time constant of increase and decrease voltage, which is applied to the LED, is close to the constant pulse time at the output of the generator and the switch. The time constant of the current increase, which is the current of LED emission, is much bigger than the time constant of its decrease. On the oscillograms of the rising edge of the voltage pulse oscillations are observed. Their amplitude exceeds the established data. The reverse voltage appears on the falling edge.

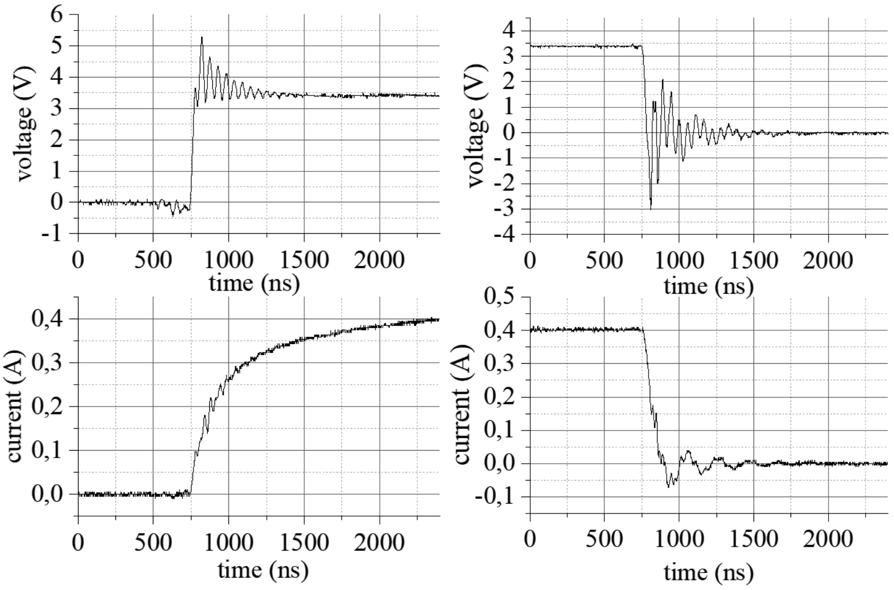

Fig.2. Oscillograms of current and voltage pulses on the rising and falling edges in an electric circuit with LED capacity

Based on the analysis of transients in an electric circuit with different types of LEDs, its equivalent wiring diagram was proposed [1]. Here, the LED is represented by a parallel link consisting of a resistance R_d, which is determined by the resistance of the LED active area, and a capacitor C_d, the capacitance of which is equal to the diffuse capacitance of the heterojunction. The resistance R_s is connected serially, it includes the resistance of the LED passive areas, as well as the resistance of the conductive elements of the electrical circuit [4].

Investigation of the kinetics of increasing and decreasing luminous flux is performed for LEDs, in which radiation of InGaN-AlGaN heterostructure (450 nm) and photoluminophore with high quantum efficiency and wide spectrum in yellow-and-orange area (500-710 nm) were used for obtaining the white glow. The chemical composition and the kinetic parameters of LED phosphors are not indicated by manufacturers, though most of them use yttrium-aluminum garnet doped with cerium as a phosphor. The maximum of its radiation is at 550-560 nm. By modifying it with gadolinium or gallium additives, the shift of its luminescence spectrum to the long-wavelength or short-wavelength side is achieved, in accordance [5,6]. The blue glow of the heterojunction, which excites the phosphor glow, in the sum with it gives cold-white or warm-white radiation.

Two-color and three-color photoluminophores are also used to achieve a high color rendering index, but their energy efficiency is lost [7 – 9].

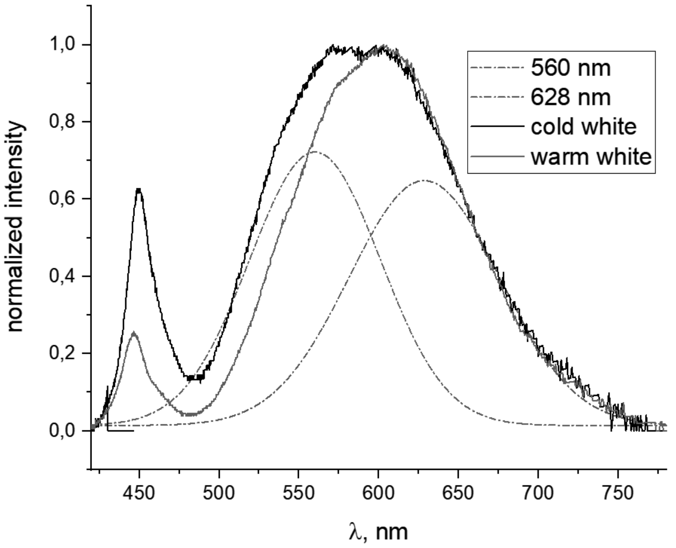

Fig.3. Glow spectra: 1) cold-white; and 2) warm-white.

Analyzing the electroluminescence spectrum of the studied LEDs, a wide band in the yellow-and-orange region was divided into two elementary bands with maxima of 560 nm and 628 nm (Fig. 4). That is, the manufacturer could use a two-color phosphor: yellow YAG:Ce and unknown red in the LEDs data. To test this hypothesis, studies of the glow kinetics in each of the individual bands, which were isolated using a monochromator were conducted. Figure 4 and Figure 5 show the oscillograms of the increase and decrease of light flux in the selected spectral areas. The graphs ln (1-I / I0) = f (t) and ln (I / I0) = f (t) are also given here [10]. They show that the kinetics of luminous flux are described by the exponential dependence, and on the attenuation curve two components - fast and slow - can be distinguished. Table 1 shows the constant growth and attenuation in each of the selected bands at a pulse frequency of 50 kHz and an amplitude of 3.4 V.

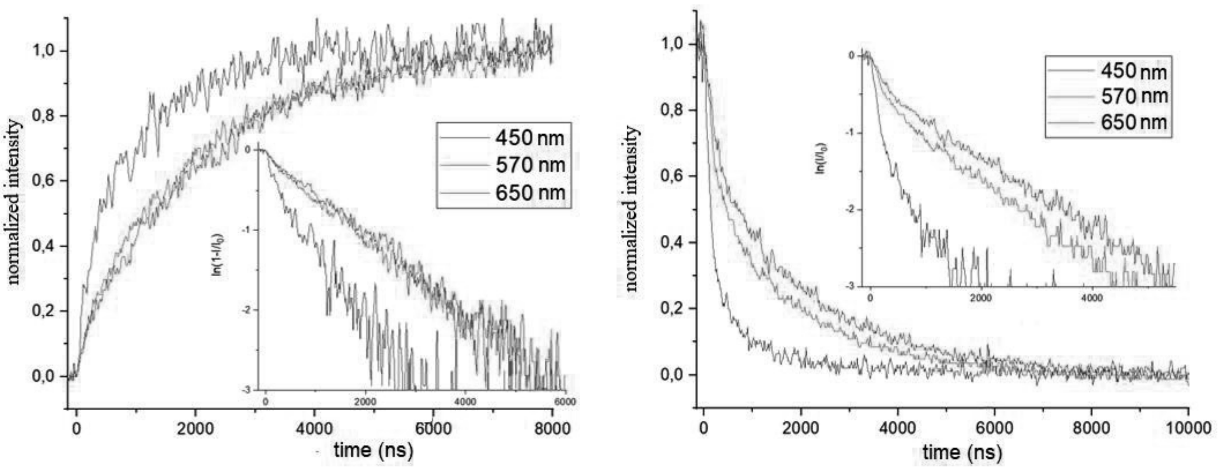

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Fig.4 The rising (a) and falling (b) edge of the light flux pulse for separate spectral areas of the warm-white ARPL-1W LED.

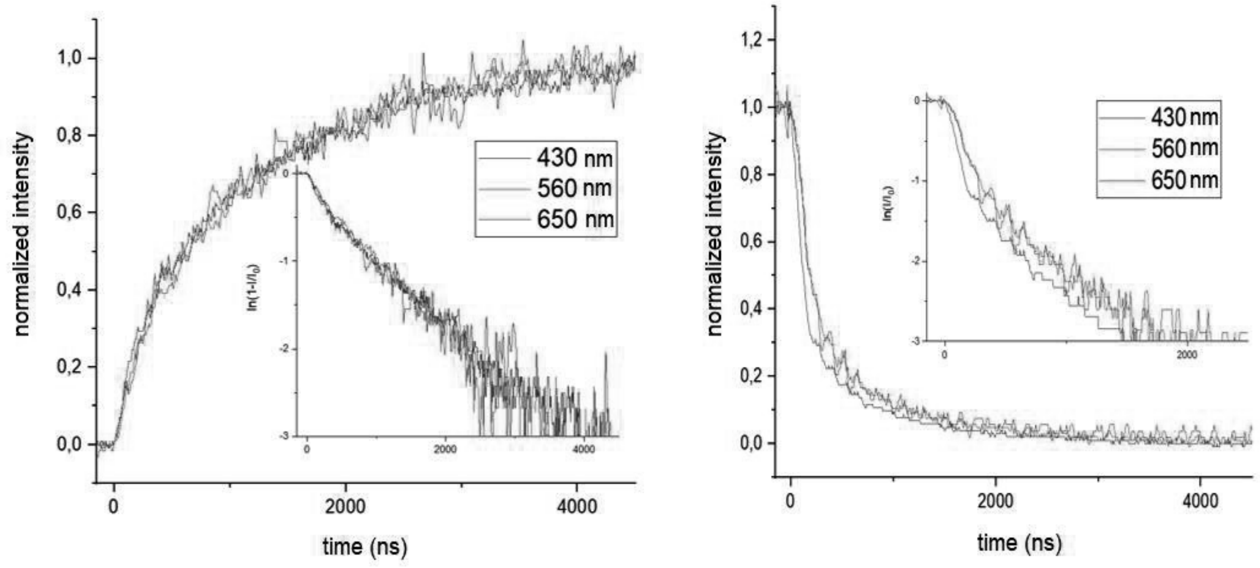

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Fig.5 The rising (a) and falling (b) edge of the light flux pulse for the separate spectral areas of the cold-white ARPL-1W LED.

Table 1 Average values of constant increase and decrease

Type	Wave length (nm)	decrease		increase	
		τ_1,(ns)	τ_2,(ns)	τ_1,(ns)	τ_2,(ns)
Warm-white 1W	452	180	800	1250	
	560	500	1900	2200	
	628	500	1950	2250	
Cold-white 1W	460	170	850	1200	
	560	300	900	1200	
	628	300	950	1230	

The kinetics of light flux growth for both blue and yellow-and-orange bands of both LED types has one component. The time constants of the increase in luminous flux in the blue band for both LED types coincide and vary in the range of 1200-1250 ns. The fast and slow components in their attenuation are very close and their time constant is in the range of 170-180 ns and 800-850 ns, in accordance.

Investigations of the luminous flux kinetics in the yellow-and-orange part of the 500-700 nm spectrum, which is connected with a one- or two-component phosphor, were performed in two spectral areas of 560 ± 5 and 630 ± 10 nm, which were isolated using a monochromator. The constant increases and attenuations in these bands for both LED types are significantly different. For warm-white LED, the constant increases of luminous flux for both bands coincide and are changed in the range of 2200-2250 ns, and for cold-white LED they also coincide and are changed in the range of 1200-1250 ns (Fig. 4, a and 5, a).

For both LED types, the decrease of luminous flux in both bands has two components: fast and slow. For warm-white LED, the time constants of the fast component for both bands are very close and they are in the range of 500-550 ns (Fig. 5, b). The same is observed for cold-white LED, their time constant is in the range of 300-350 ns (Fig. 6, b). The slow components of both bands for warm-white and cold-white LED differ significantly, from 2200-2250 and 1200-1250 ns, in accordance, although for each in particular they coincide (Fig. 4, b and 5, b).

It was found that the kinetics of the studied LED glow depends on the frequency of the pulse power supply. To do this, measurements of the increase and decrease of the luminous flux in all selected spectral areas when changing the pulse frequency from 1 to 500 kHz were performed.

Figure 6 shows the frequency dependences of the time constant of the luminous flux increase for warm-white (a) and cold-white (b) LED ARPL-1W. As the frequency τ increases for both bands in the yellow-and-orange area of the spectrum, it decreases from 2250 ns at 10 kHz to 480 ns at 400 kHz for warm-white LED, and from 1300 to 400 ns for cold-white LED. In the blue area for both LEDs the frequency τ decreases from 1250 to 450 ns.

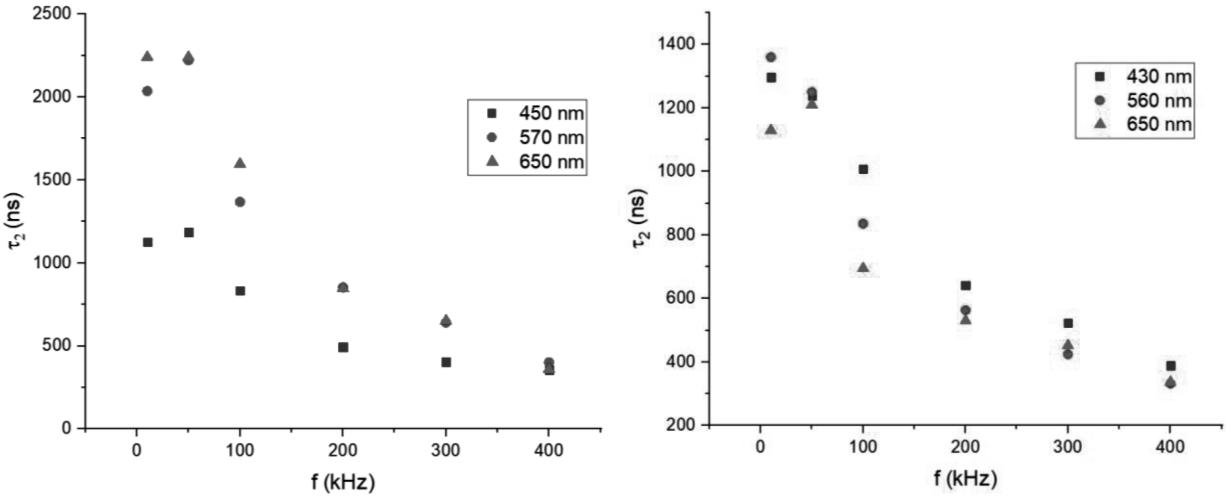

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Fig. 6. Frequency dependences of the time constant in light flux increase of warm-white (a) and cold-white (b) LED ARPL-1W.

The frequency dependences of the luminous flux decrease for both LED types are shown in Fig. 7 and Fig. 8. The decrease time constant of the slow component for both selected bands, at increased frequency from 10 to 400 kHz, decreases from 2050 to 450 ns for warm-white LED and from 1050 to 400 ns for cold-white LED. The fast component constant also decreases with increasing frequency from 550-600 to 200-230 ns for warm-white LED, and from 300-320 to 180-200 ns for cold-white LED. In the blue area the slow component constant decreases with a frequency of 850 to 500 ns for warm-white LED, and from 1050 to 400 ns for cold-white LED. The change of the fast component constant for both LED types is very close and occurs in the range from 180 to 120 ns.

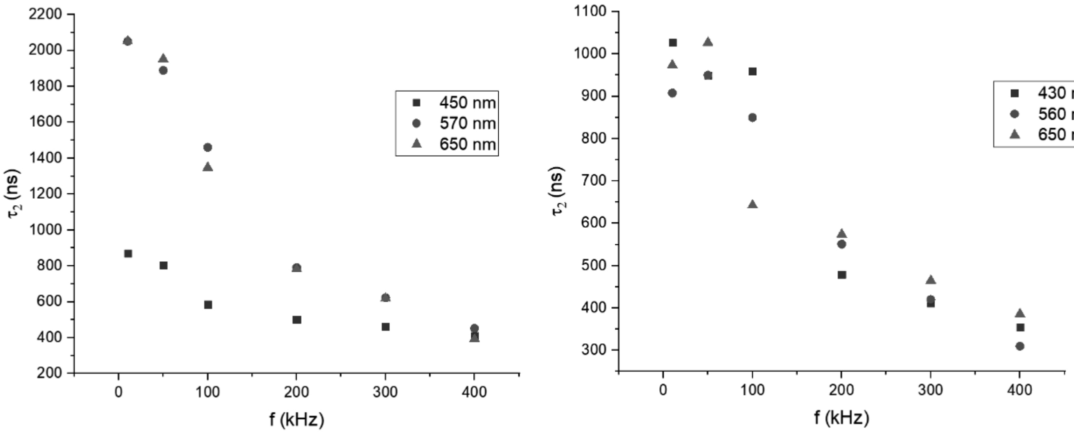

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Fig. 7. Frequency dependences in the time constant of slow component decrease of the light flux in warm-white (a) and cold-white (b) LED ARPL-1W.

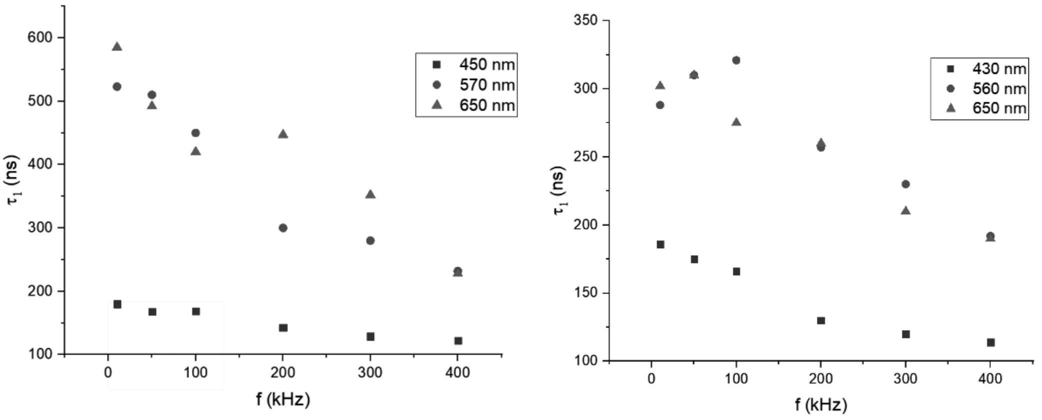

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Fig. 8. Frequency dependences in the time constant of fast component decrease of the light flux in warm-white (a) and cold-white (b) LED ARPL-1W.

Experimental studies on the effect of current pulse amplitude and voltage on the glow kinetics of the studied LEDs were performed. Fig. 9 and fig. 10 show the dependences of the time constant of increase and decrease of the LED luminous flux on the amplitude of voltage and current pulses. In the yellow-and-orange area for warm-white LED the time constant of increase in luminous flux in selected spectral areas varies within 2200 ± 100 ns with increasing amplitude of voltage and current pulses, and for the band in the blue area it is 1150 ± 50 ns (Fig. 9, a). For cold-white LED with increasing amplitude of pulses, the time constant of increase in luminous flux is almost unchanged, although the relative scatter of experimental data is greater than 1220 80 ns (Fig. 9, b).

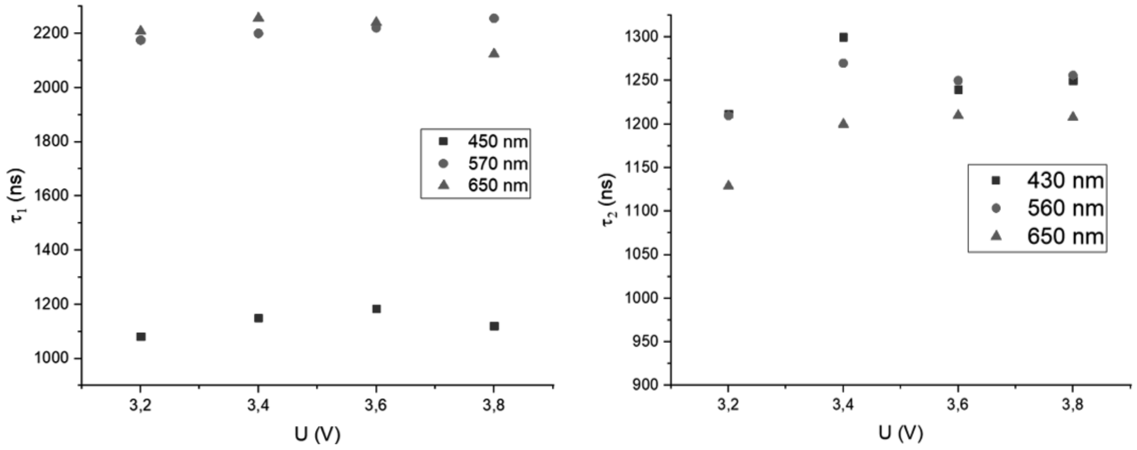

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Fig. 9. Dependence of the time constant of light flux increase on the amplitude of voltage and current pulses of warm-white (a) and cold-white (b) LED.

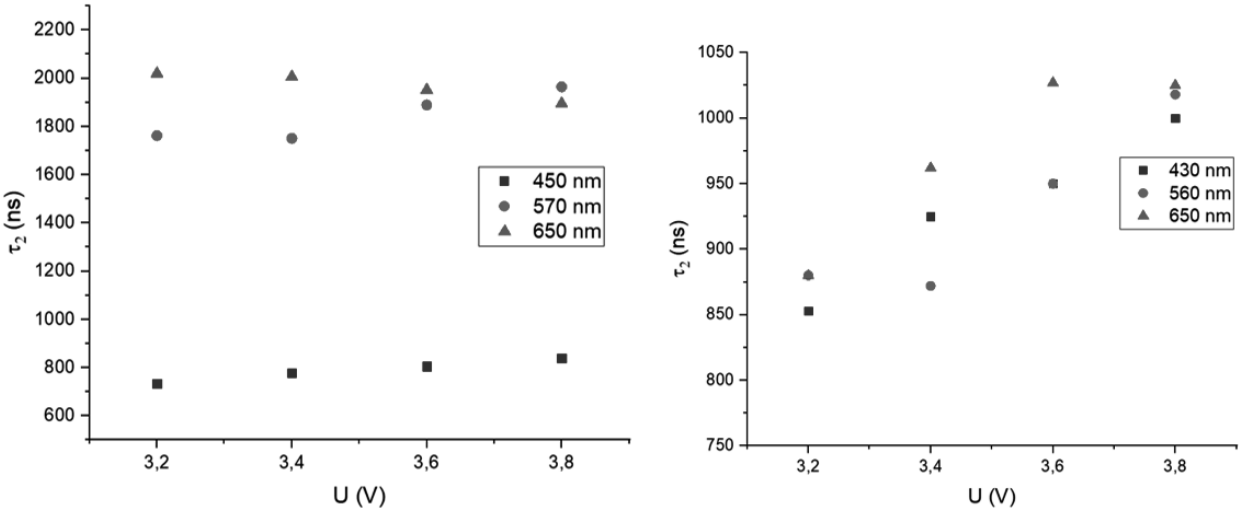

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Fig. 10. Dependence of the time constant of light flux decrease on the amplitude of voltage and current pulses of warm-white (a) and cold-white (b) LED.

The time constant of the slow component of the decrease in luminous flux in the yellow-and-orange area for warm-white LED varies within 1900 ± 100 ns, and in the blue area it varies within 800 ± 50ns. For cold-white LED in both blue and yellow-and-orange parts of the spectrum, it increases from 850 ± 50 to 1020 ± 50 ns (Fig. 10).

From the analysis of the luminous flux kinetics in two selected spectral bands of 560 and 628 nm, obtained by decomposing the yellow-and-orange band of warm-white and cold-white LED and its behavior with the changing frequency of the pulse power supply and pulse amplitude, it can be stated that in white LED such as FYL-3014 and ARPL-1W the manufacturer used one-component phosphor YAG:Ce. The shift of its luminescence maximum into the short-wavelength area of the spectrum, which takes place for cold-white LED, was achieved by introducing Ga and choosing x in $Y_3Al_{5-X}Ga_XO_{12}$:Ce.

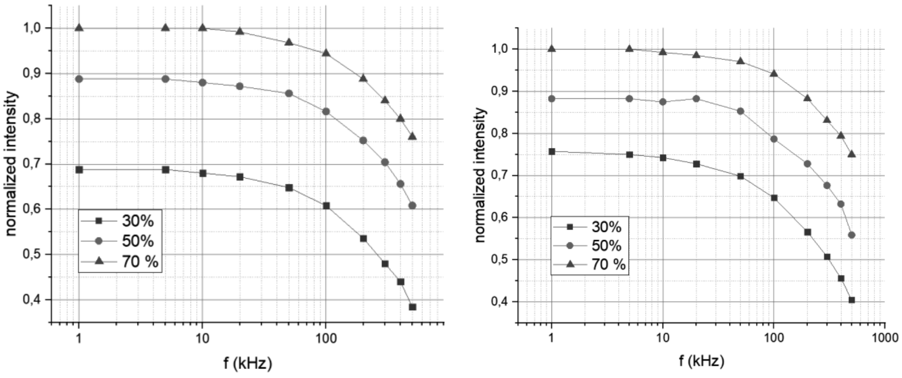

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Fig. 11. Dependence of light flux of a) warm-white and b) cold-white LED on the frequency and degree of pulses filling.

In addition to studies of the light flux kinetics of selected LEDs, a study of the luminous flux magnitude from the pulse frequency and the degree of their filling was performed. From 1 kHz to 10 kHz the luminous flux hasn’t been changed. It correlates well with the time constant of the increase. It changes less at 70% filling than at 50% and 30%. When the pulse frequency increases to 100 kHz and fills 70%, it decreases by 5%, while at 50% and 30% it decreases by 10%.Thus, based on the analysis of the glow kinetics of white LEDs such as FYL-3014 and ARPL-1W and the frequency dependence of their luminous flux, it follows that the most energetically favorable frequency range of their pulse power is from 1 to 100 kHz. This will let approximate the operating time of the elements in the PWM power supply circuits to the operating time of the main circuit element - the LED.

4.Conclusions

The time constant of increase and decrease in the luminous flux in the yellow-and-orange photoluminescence band of warm-white LED is twice as much as the time constant for cold-white LED. As the frequency of the pulsed power supply increases, the time constant of the increase and decrease in the luminous flux in this band for both LED types decreases to 350-400 ns at 400 kHz.

The kinetic parameters of the luminous flux in the blue band remain the same for both types of LEDs. As the pulse frequency increases, the time constant of increase and decrease decreases equally for both types of LEDs.

Based on the analysis of light flux kinetics in the yellow-and-orange luminescence band of white LEDs FYL-3014 and ARPL-1W and its behavior with changes in the frequency of the pulse power supply and the amplitude of the pulses, it is shown that one-component phosphor YAG:Ce is used.

The most energetically favorable frequency range of LED pulsed power supply FYL-3014 and ARPL-1W is warm-white and cold-white glow from 1 to 100 kHz.

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