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Kinetics of narrow-spectrum LED glow under pulsed power

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Abstract. The results of experimental investigations of the glow kinetics of narrow-spectrum LEDs based on InGaN-GaN 450 and 520 nm and AlGaInP-GaAs 625 nm structures are presented. The increase and decrease of the light flux intensity under pulsed power are described by exponential dependences containing fast and slow components. The time constants of both components decrease with the increase of the pulse frequency for all three types of LED samples. The time constant of the slow component decreases with the increase of the current and voltage pulse amplitudes. The maximum light output on the frequency dependences of LED energy characteristics is observed at the frequency of 75…100 kHz. Further frequency increase results in the decrease of the LED energy efficiency. The obtained results are explained based on the LED equivalent electrical and energy circuits.

Keywords: light-emitting diode (LED), pulse-width modulation, energy efficiency, attenuation coefficient.

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1. Introduction

Powering LEDs by pulsed power supplies with pulse-width modulation is the most common method enabling control of the LED brightness by well-known technical means. Leading manufacturers of LED light sources (LED) claim that the service life of their devices can reach 100 thousand hours [1–3]. In this case, the luminous flux decreases by only 30%. Since the operation lifetime of lighting equipment is defined by both LED and power supply operation life, the same requirements must be also met by the electrical converter elements. Unfortunately, weak points of pulsed power supplies are the output units with inductive-capacitive filters. As a rule, electrolytic capacitors with the operation lifetime of 2 to 5 thousand hours are used there [4]. After this time, such capacitors lose their capacity resulting in light flux pulsations [4, 5]. The reliability issue becomes even more serious when lighting systems with more than one LED power supply channel are created. In such systems, deactivation of the operation mode of one power supply channel can completely disrupt system operation [6]. One of the ways to solve this problem is to increase the frequency of pulsed power supplies. Such frequency increase makes it possible to use modern low-capacity filter capacitors with long service life [5]. The mentioned problem is extremely important not only for LED power supply systems but also for other electrical circuits with PWM and areas with electrolytic capacitors based filters. In particular, one of such circuits is considered in [7].

Another important issue is the use of LEDs as light sources for the operation of local optical communication systems at very short (< 1 m) to medium (5 km) distances as well as for monitoring traffic flow and road accidents [8, 9]. To select the maximum frequency of pulsed power supplies for LED light sources, the information about the kinetics of their electrical and lighting characteristics is required. Unfortunately, this problem is hardly covered in the literature [10, 11]. Therefore, the goal of this paper is to study experimentally the glow kinetics of LEDs based on InGaN-GaN 450 and 520 nm and AlGaInP-GaAs 625 nm structures as well as the transient processes in electric circuits with commercially available 1 and 3 W SD FYL-3014 and ARPL-1Wpowered by P-shaped pulses with width modulation [12].

2. Experimental setup

The spectral and dynamic characteristics of LEDs were measured using the experimental setup, the block diagram of which is shown in Fig. 1.

To study energy characteristics, the light source (*4*) is placed into the integrated photometer (*1*). Electrical signal from the photodetector (*5*) is transmitted to the digital SEA C8-22M/1 oscilloscope (*9*). The adjustable

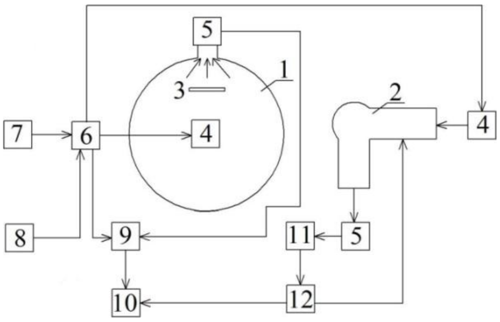


Fig. 1. Block diagram of the experimental setup: *1* – integrated photometer, *2* – monochromator UM-2, *3* – shield, *4* – investigated light source, *5* – photodetector, *6* – switching device, *7* – adjustable DC voltage source SW3010D, *8* – SIGLENT SDG 1050 generator, *9* – SEA C8-22M/1 oscilloscope,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

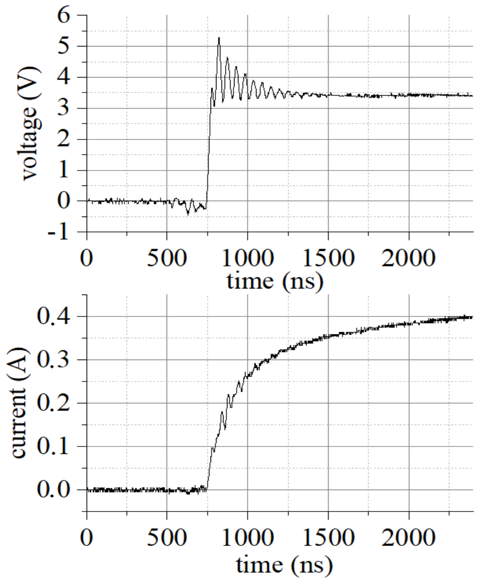
DC voltage source SW3010D (*7*), SDG 1050 signal generator (*8*) and electronic switch (*6*) are used to commutate current up to 10 A and voltage up to 100 V. This makes it possible to power light sources with both DC current and in the pulsed mode with the pulse frequency up to 1 MHz and different fill factors. The current, voltage, amplitude and pulse duration are controlled by a digital SEA C8-22M/1 oscilloscope. The measurement results are processed and stored by a personal computer.

AUM-2 monochromator is used to study the LED spectral distribution and to separate spectrum parts. The light pulse is measured by a photoelectron multiplier (PhEM) FEU-85 used as the photodetector (*5*). The signal from the PhEM is fed to the operational amplifier (*11*) operating in the current-voltage converter mode. The monochromator is operated using ARDUINO NANO (*12*).

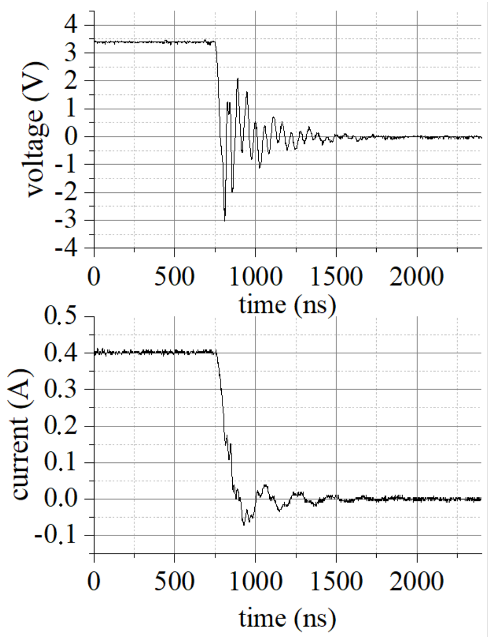
3. Electrical and lighting characteristics under pulsed power

Before investigating LED lighting characteristics, their electrical parameters under pulsed power were measured. Two types of LEDs, namely FYL-3014 and ARPL-1W emitting blue (450 nm), green (520 nm) and red (625 nm) light with known spectral distributions [12], were used for the measurements. 1WLEDs were powered by a SIGLENT SDG 1050 generator, and an electronic key was additionally used to power 3W LEDs [13].

The oscillograms of current and voltage pulses at the front and rear edges in the electric circuits containing the investigated LEDs are shown in Fig. 2. The oscillating nature of the transient process indicates the presence of reactive elements in the electrical circuit. These elements are contained in the LED structure. The time increase and decrease constants of the voltage applied to the LEDs are close to the pulse time constant at the output of the generator and the switch. The time increase constant of current being the LED emission current is much greater than the time decrease constant. Oscillations are observed on the oscillograms of the front edge of the voltage pulse. The amplitudes of these oscillations exceed the established value. The voltage has the opposite polarity at the rear edge. Based on the analysis of transient processes in the electric circuits of different LED types, the equivalent electrical circuit shown in Fig. 3 [13] is proposed. Here, the LED is represented by a parallel link consisting of the resistance R_d defined by the resistance of the active LED area and the capacitor C_d with the capacity equal to the diffuse heterojunction one. These elements are connected in series with the resistance R_s, which includes the resistance of the LED passive areas and the resistance of the electrical circuit conductive elements. P-shaped voltage



(a)



(b)

Fig. 2. Oscillograms of current and voltage pulses at the front (a) and rear (b) edges in the electric circuit with LED load.

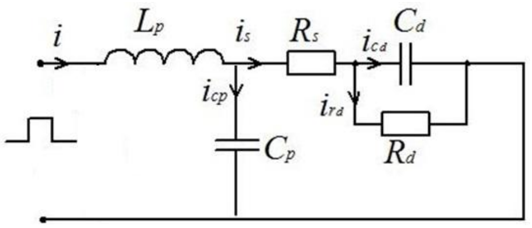


Fig. 3. Equivalent scheme of LED with batteries.

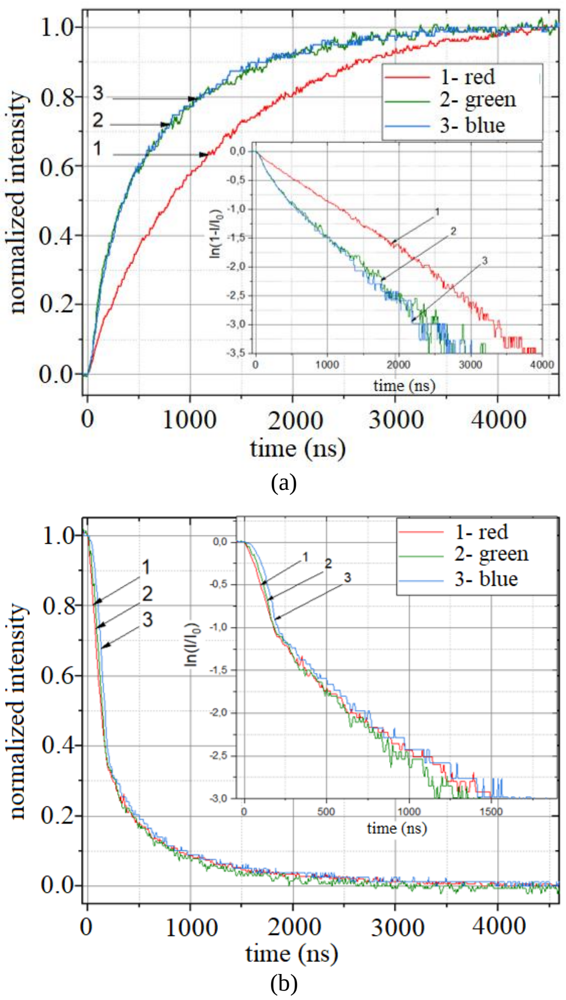


Fig. 4. Front (a) and rear (b) edges of a FEM photocurrent pulse of single-color LEDs ARPL-1W.

pulses are supplied to the LED through a coaxial cable, the equivalent circuit of which is represented by the $R_P C_P L_P$–area, and a series resistor R_s [14].

The kinetics of the increase and decrease of LED luminous flux is studied using pulses of photodetector photocurrent both at the output of the monochromator and integrated photometer. The front (a) and rear (b) edges of PhEM photocurrent pulses for single-color LEDs ARPL-1W are shown in Fig. 4. The data are also presented in semi-logarithmic scale showing the exponential nature of the LED glow kinetics. The time constants τ are determined from these graphs. Two components, namely fast and slow, are observed in the curves corresponding to the increase and decrease of light flux. The values of these constants at the pulse frequency of 50 kHz are presented in Table.

The proportion (area) of the fast component in the increase curves is very small, 0.1-0.15 of the light pulse amplitude. For several investigated samples (red glow LEDs), it is totally absent.

The kinetics of the investigated LEDs is found to depend on the frequency of pulsed power supply. Therefore, we measured the kinetics of increase and decrease of luminous flux changing the pulse frequency from 1 to 500 kHz.

The frequency dependences of the slow component of the increase (a) and decrease (b) of luminous flux for the LED ARPL-1W are shown in Fig. 5. It can be seen from this figure that the increase and decrease time constants of a light pulse decrease at the increase of the pulse frequency for all three monochromatic LED samples. The increase time constant changes in the wide strange, from 1200 to 400 ns, for the red LED. For all three LEDs, the maximum time constant is observed within the frequency range of 50…100 kHz.

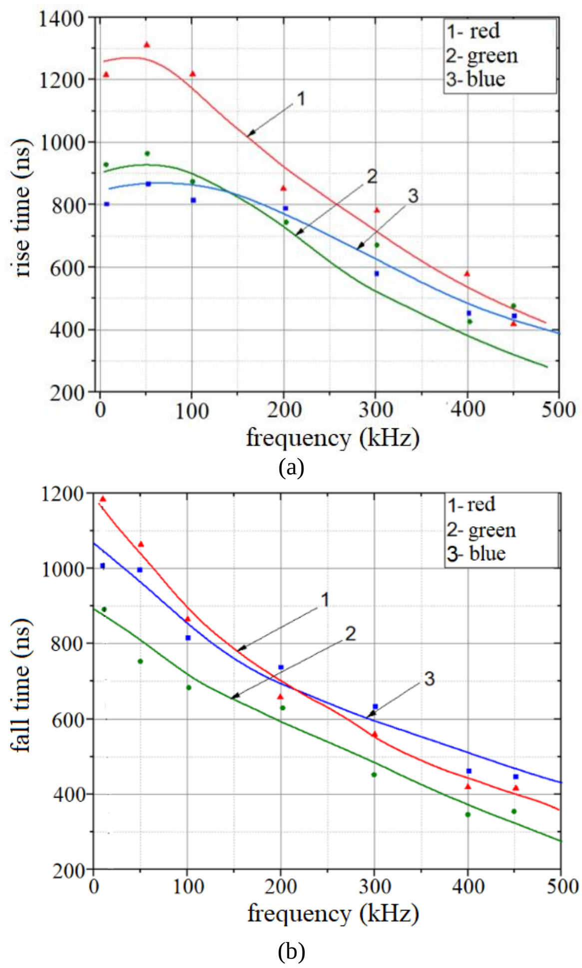


Fig. 5. Pulse frequency dependences of the slow component of increase (a) and decrease (b) for the ARPL-1W type LED.

Table. Decrease and increase constants of luminous flux at the pulse frequency of 50 kHz.

Glow	LED type, W	Decrease		Increase	
		τ_1, ns	τ_2, ns	τ_1, ns	τ_2, ns
Red	1	90	420	1200	
	3	280	560	1500	
Blue	1	100	490	1100…1200	
	3	270	790	380	1200
Green	1	250	500	1000	
	3	240	580	500	1130

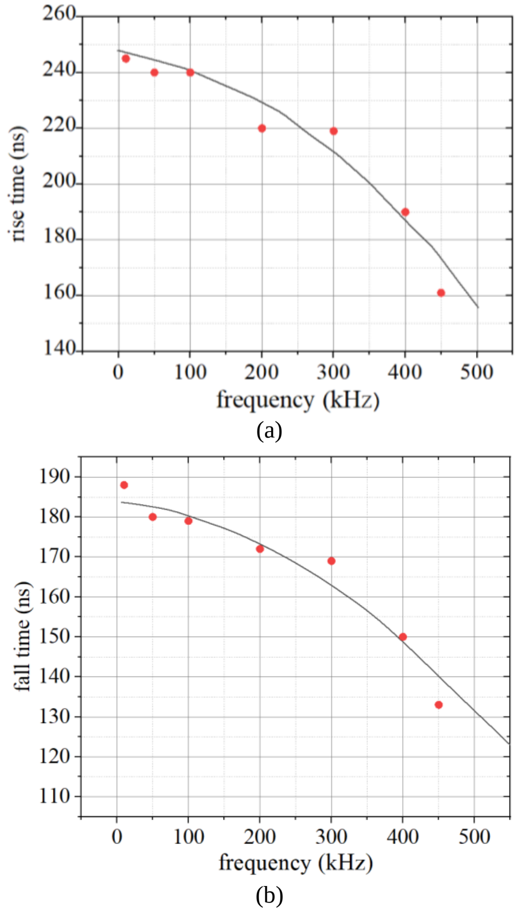


Fig. 6. Frequency dependence of the fast component of luminous flux increase (a) and decrease (b) for the blue ARPL-1W type LED.

The pulse frequency dependences of the increase and decrease time constants of the fast component for the blue LED are shown in Fig. 6. The same dependences are observed for the green and red LEDs. As can be seen from this figure, the time constant of luminous flux decreases from 245 to 155 ns with increasing the frequency. For attenuation, it decreases from 185 to 115 ns when the pulse frequency changes from 10 to 500 kHz.

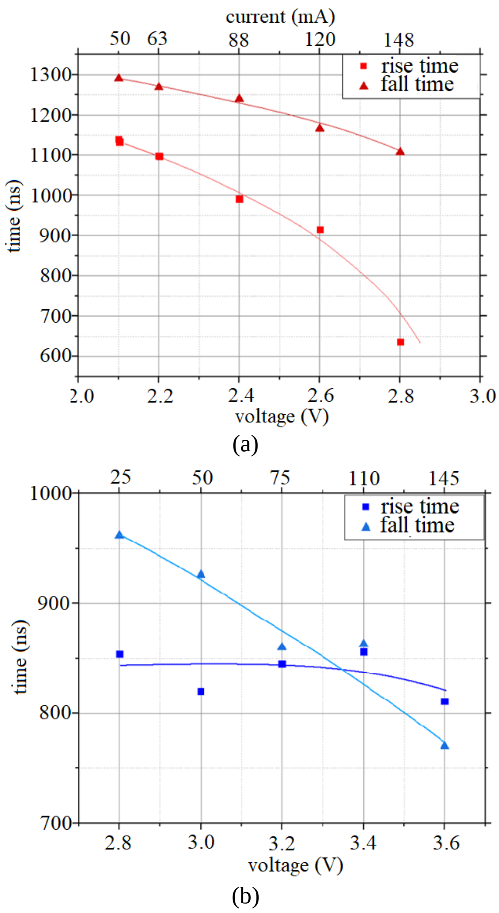


Fig. 7. Dependences of the light flux increase and decrease constants on the amplitude of voltage pulses and supply current for (a) red and (b) blue LEDs.

The influence of the amplitude of power pulse on the LED glow kinetics was also studied. The dependences of the slow components of the luminous flux increase and decrease constants for the red (625 nm) and blue (450 nm) LEDs on the voltage pulse amplitude and emission current at the frequency of 50 kHz with 50% filling are presented in Fig. 7. It can be seen from this figure that the slow component of both luminous flux increase and decrease constants decreases with the increase of the amplitude of voltage pulse and emission current. The nature of the change of luminous flux remains unchanged when the filling at latitudinal modulation changes. Similar results are also obtained for the green (520 nm) LED.

The energy characteristics of the LEDs were measured using an integrated photometer. Frequency dependences of the luminous flux expressed in relative units at 50% filling of pulsed power are shown in Fig. 8. Up to 100 kHz, the luminous flux changes in the range of 10 to 25%. Further increase in the pulse frequency results in its sharper decrease.

In the discussion of the experimental results we assume that the LED glow kinetics under pulsed power is described by exponential dependence and has fast and slow components. The proportion of the fast component

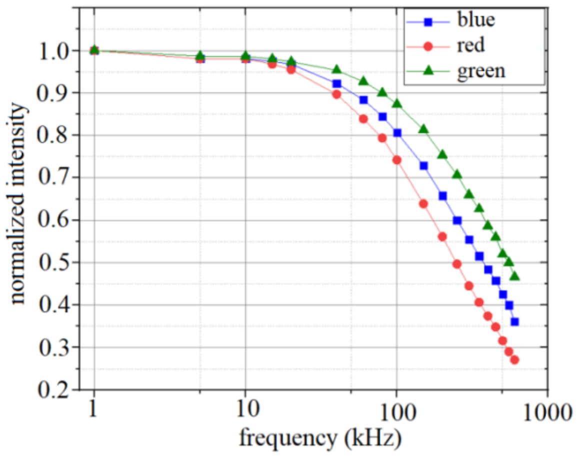


Fig. 8. Dependences of LED luminous flux on pulsed supply frequency.

in the growth curves is very small, 0.1-0.15 of the light pulse amplitude, and may be absent for several investigated samples. The slow increase of the emission current indicates the presence of a slow component of the luminous flux increase, although the time constant of the luminous flux increase is slightly greater than that of current.

It can be seen from the current and voltage oscillograms (Fig. 2) that the rear edge of a voltage pulse exhibits harmonic oscillations. The reverse bias voltage is applied to the transition resulting in the appearance of reverse current. That is, extraction of electrons and holes from the active area to the *n*- and *p*-areas of the heterojunction takes place along with recombination. This results in the sharp decrease of the concentration of charge carriers in the active area, affecting the rate of emitting recombination. This is manifested by the presence of the fast component in the attenuation kinetics of LED luminous flux. The time constants of the long-term components of the luminescence kinetics of the investigated LEDs most probably characterize the life-time of minority charge carriers in the LED active area.

To determine the maximum pulse frequency f and filling value D, the time constant τ of the increase and decrease of luminous flux should be taken into account. If we assume that the transient process in an electric circuit with a LED ends within 5τ, then $f_{max} = 5\tau/D$. For the investigated narrow-spectrum LEDs at $D = 0.5$, f_{max} does not exceed the pulse frequency of 75 to 100 kHz, which is confirmed by the experimental results. With the increase of the frequency of pulsed power supply, the pulse duration τ_i becomes too short to complete the transient processes. This can reduce the quantity of carriers injected in the LED. Moreover, these carriers have no time to diffuse deep into the active area and concentrate mainly in the thin layer at the heterojunction boundary thus increasing the number of extracted carriers. This results in the decrease of the luminous flux with the increase of the pulse frequency, which affects the LED energy efficiency.

4. Conclusion

In this work, the glow kinetics of narrow-spectrum LEDs based on InGaN-GaN 450 and 520 nm and AlGaInP-GaAs 625 nm structures are investigated.

The kinetics of the increase and decrease of luminous flux are described by exponential dependences containing fast (150…200 ns) and slow (1000…1200 ns) components. The proportion of the fast component in the growth curves is 0.1-0.15 of the light pulse amplitude. The fast component is absent for several investigated samples.

The time constants of both fast and slow components of the increase and decrease of luminous flux decrease with the increase of the amplitudes and/or frequency of current and voltage pulses.

Harmonic oscillations at the rear edge of a voltage pulse due to the transient process result in the generation of reverse current in the LED and cause attenuation of the fast component of luminous flux.

The slow component of light attenuation is defined by the lifetime of minority carriers injected into the LED active region.

The maximum luminous flux on the frequency dependence of LED energy characteristics is observed at the frequency of 75 to 100 kHz. It decreases with further increase of the frequency of a pulsed power supply.

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Authors' contributions

All authors discussed the results and implications and commented on the manuscript at all stages.

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Кінетика свічення вузькоспектральних світлодіодів при імпульсному живленні

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Анотація. Наведено результати експериментальних досліджень кінетики свічення вузькоспектральних світлодіодів (СД) на основі структур InGaN-GaN 450 і 520 нм та AlGaInP-GaAs 625 нм. Наростання та спадання світлового потоку при імпульсному живленні описується експоненціальною залежністю і має швидку та повільну складові. Із зростанням частоти імпульсів постійна часу обох складових наростання та спадання світлового потоку зменшується для усіх трьох типів зразків СД. Із збільшенням амплітуди імпульсу струму та напруги постійна часу повільної складової зменшується. На частотній залежності енергетичних характеристик СД максимум світлового потоку знаходиться на частоті 75…100 кГц. Подальше зростання частоти приводить до спадання енергетичної ефективності СД. Пояснення результатів проведено на основі еквівалентної електричної та енергетичної схеми СД.

Ключові слова: світлодіод, широтно-імпульсна модуляція, енергетична ефективність, коефіцієнт затухання.