Relationship between the luminous flux drop of LED matrices during tests with thermal resistance and parameters of the emission spectrum

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Abstract. Accelerated tests of LED matrices under the action of electric current under conditions of thermal cycling and vibration were carried out. It was determined that the value of the luminous flux decay correlates with the junction-to-case thermal resistance of the matrices and the value of the K_S coefficient, which determines the ratio of the luminous flux of optical emission in the near infrared region of the spectrum from 760 nm to 900 nm to the luminous flux in the spectrum range from 470 nm to 760 nm. The correlation coefficient between the luminous flux decay and the junction-to-case thermal resistance is 0.7, and the correlation coefficient between the luminous flux decay and the K_S coefficient is 0.48.

Исследование связи темпа спада светового потока светодиодных матриц с тепловым сопротивлением и параметрами спектра излучения

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Аннотация. Проведены ускоренные испытания светодиодных матриц под действием электрического тока в условиях термоциклирования и вибрации. Определено, что

величина спада светового потока излучения коррелирует с тепловым сопротивлением переход-корпус матриц и значением коэффициента K_S, определяющего отношение светового потока оптического излучения в ближней инфракрасной области спектра от 760 нм до 900 нм к световому потоку в диапазоне спектра от 470 нм до 760 нм. Коэффициент корреляции между спадом светового потока излучения и тепловым сопротивлением переход-корпус составляет 0,7, а коэффициент корреляции между спадом светового потока излучения и коэффициентом K_S составляет 0,48.

Introduction

One of the promising areas of application of LED matrices is their use in the lighting equipment of aircraft. Currently, LED matrices are beginning to be used both in internal and external lighting equipment, including taxi lights, takeoff and landing lights, and navigation beacons. The service life and reliability of such devices largely depend on the operating conditions, primarily on the ambient temperature and current load mode [1−3]. LED devices used in on-board lighting and signaling equipment of aircraft are subject to sharp changes in ambient temperature in a wide range over a short period of time. However, to date, the relationship between the reliability of LED matrices when operating under thermal and electrical cycling conditions and thermal characteristics has not been sufficiently investigated. In this regard, the task of investigation the degradation processes of LED matrices when operating in the electrical cycling mode and under temperature change conditions and determining the parameters by which it is possible to identify LED matrices prone to accelerated degradation is relevant.

Materials and Methodes

The LED matrices of the GW P9LR31.EM - DURIS S 8 type, consisting of eight series-connected crystals, are investigated. The matrix supply voltage is 24 V, the maximum current is 200 mA. The matrices were tested for 16 hours under electrical and thermal cycling and vibration conditions. The duration of one temperature cycle was 4 hours: the temperature in the test chamber was maintained at T = +115 °C for 1.5 hours, at T = -60 °C for 1.5 hours, the temperature changed over 30 minutes. The duration of one electrical cycle was 30 minutes: a current of 190 mA was passed through the matrices for 15 minutes, and the matrices were switched off for 15 minutes. Electrical and thermal cycling of the matrices was accompanied by broadband vibration of 6.8 g. The accelerated test mode is equivalent to 1300 hours of LED matrices operation under natural operating conditions of an aircraft.

During the tests, the changes in the luminous flux and emission spectra, junction-to-case thermal resistance, current-voltage characteristics of the LED matrices were monitored. The luminous flux and emission spectra were measured in the photometric sphere using an OL770 spectroradiometer at a current of 30 mA. The $I-V$ characteristics were measured using an automated setup using the LabView graphical programming environment, consisting of a Keithley 6500 precision multimeter used to measure the current and a Tektronix DMM4040 digital multimeter used to measure the voltage on the LED matrix. The junction-to-case thermal resistance R_{TJ-C} of the LED matrices was measured according to the method presented in [4, 5]. The R_{TJ-C} thermal resistance determines the overheating temperature of the active region of the matrix crystals relative to the case temperature.

Results and discussion

The emission spectrum of the LED matrix of the investigated type is shown in Fig. 1.
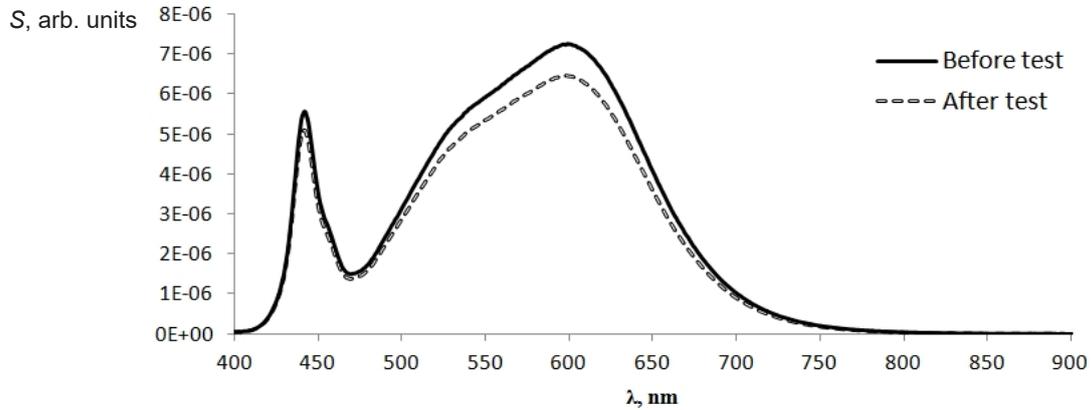

Fig. 1. LED matrix emission spectrum

The spectral section in the wavelength range from 400 nm to 470 nm is formed by the emission of the matrix crystals. The spectral section in the wavelength range from 470 nm to 900 nm is formed by the luminescence of the phosphor covering the matrix crystals. The blue light of the matrix crystals is absorbed by the phosphor. The excited phosphor ions return to the ground state, emitting photons in the yellow-green region of the visible spectrum. Partial reabsorption is possible: some of the photons emitted by the phosphor ions (especially photons in the short-wavelength part of the luminescence spectrum) are absorbed by the phosphor. These reabsorbed photons can re-excite the ions in the phosphor. Since the luminescence spectrum of phosphor ions is broad and shifted to the long-wave region, the secondary emitted photon will have a longer wavelength than the initially reabsorbed photon. This phenomenon is associated with the Stokes shift. In addition, this process can occur repeatedly within a phosphor particle or between particles. Thus, the long-wave section of the phosphor emission spectrum in the near infrared range, approximately from 760 nm to 900 nm, is mainly formed due to secondary emission [6−8].

A coefficient has been introduced that determines the ratio of the luminous flux of optical emission in the near infrared region of the spectrum from 760 nm to 900 nm to the luminous flux in the spectrum range from 470 nm to 760 nm:

$$K_S = \frac{\int_{760}^{900} S(\lambda)d\lambda}{\int_{470}^{760} S(\lambda)d\lambda} 100\%. \tag{1}$$

It was found that the K_S coefficient is a temperature-sensitive parameter. For this purpose, the emission spectra of the matrices were measured in a Combitherm CH 3-150 thermostat in the temperature range from 30 °C to 70 °C. The emission spectra of the LED matrices were measured by an Ocean Optics USB2000+VIS-NIR spectrometer. To eliminate self-heating of the matrix crystals during spectrum measurement, a small current of 300 μA was passed through the matrices. It is evident from Fig. 2 that K_S increases with increasing temperature, and the $K_S(T)$ dependence is nonlinear.

As the temperature increases, the emission spectrum of the LED matrix crystals shifts to the long-wave region. The absorption spectrum of the phosphor also shifts to the long-wave region. In this case, the phosphor becomes capable of absorbing photons with lower energy, which leads to an increase in the probability of reabsorption with increasing temperature. Thus, as the temperature increases, the proportion of emission in the near infrared region of the spectrum increases relative to the radiation formed by the phosphor.

A positive correlation between the value of the K_S coefficient and the junction-to-case thermal resistance was found in a sample of 60 matrices: the correlation coefficient is 0.65.
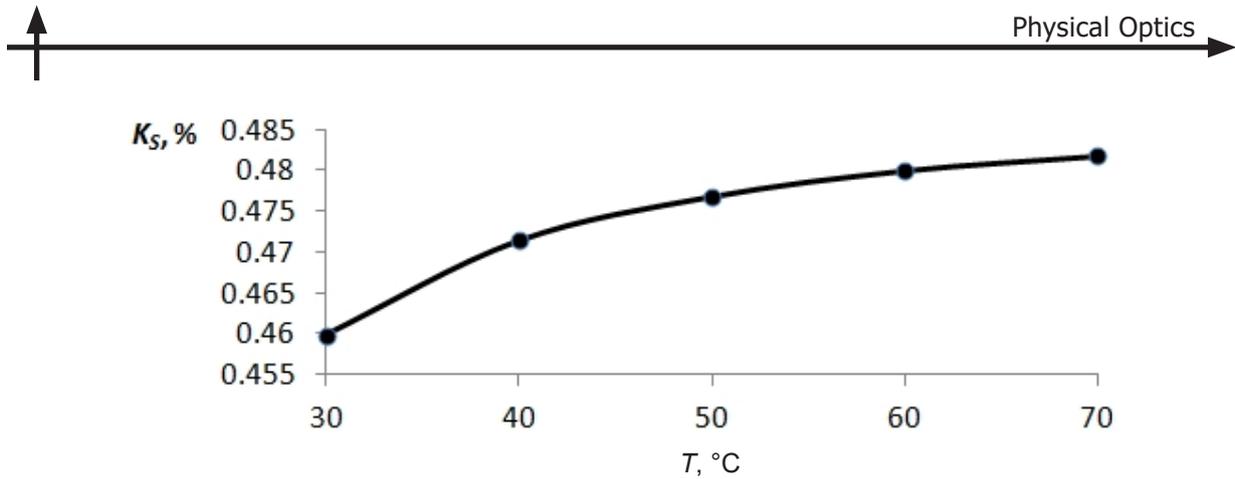
Fig. 2. Dependence of the coefficient K_S on temperature

Based on the results of thermal resistance measurements, six matrices were selected from 60 matrices whose thermal resistances cover the range from the minimum to the maximum value within the investigated sample. The minimum is 2.0 K/W, the maximum is 3.3 K/W. These six matrices were tested in the mode presented above. After the tests, all six matrices experienced a decrease in luminous flux. The smallest decrease was observed in matrices No. 7 and 30, by 4.90%, and the largest in matrices No. 11, 37 and 51 (Table 1).

Table 1

Results of measurements of LED matrix parameters

LED array	R_{TJ-C}, K/W	K_S, %	Luminous flux drop $\Delta\Phi$, %
7	2.1	0.410	4.90
11	3.3	0.415	5.39
13	2.0	0.405	4.93
30	2.1	0.413	4.90
37	2.7	0.408	5.71
51	2.6	0.417	5.65

The decrease in luminous flux correlates with the value of the junction-to-case thermal resistance (correlation coefficient 0.7) and with the value of the K_S coefficient (correlation coefficient 0.48): those matrices in which the active region overheating temperature is higher have a higher degradation rate.

During the testing of LED matrices, the emission intensity decreases in the entire range of the emission spectrum (Fig. 1). The decrease in the range of 400−470 nm is due to the degradation of crystals, and the decrease in the range of 470−900 nm is due to the decrease in the emission intensity of crystals and the degradation of the phosphor [9].

Conclusion

It is shown that the value of the luminous flux drop of LED matrices correlates with the values of the junction-to-case thermal resistance and the value of the coefficient determining the share of the luminous flux of optical emission in the near infrared region of the spectrum to the luminous flux of emission formed by the phosphor. These parameters can be used to identify potentially unreliable LED matrices prone to accelerated degradation.

It is also shown that it is more appropriate to consider the degradation of white LED emission as the combined degradation of the crystal-phosphor system, although the crystal is the dominant component of this system due to the fact that it is the initiating factor of the phosphor emission.

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