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The influence of temperature on optical and electrical parameters of medium and high power LEDs

***Abstract**: The article presents the issues connected with the problem of high temperatures influence on LED diodes. It presents the results of the research showing the impact of the temperature on the electrical and optical parameters of diodes. The thesis also includes the information concerning the selection of the heat dissipating systems in order to maintain proper operation temperature and avoid the consequences connected with LED diodes overheating.*

***Streszczenie.** W artykule przedstawione zostały zagadnienia związane z problemem działania wysokich temperatur na diody LED. Zaprezentowano wyniki badań ukazujące wpływ temperatury na parametry diod. Praca zawiera również informację na temat doboru układów rozpraszających ciepło w celu zachowania odpowiedniej temperatury pracy diod (**Wpływ temperatury na parametry optyczne i elektryczne diod LED średniej i dużej mocy**).*

Keywords: diodes, LED, optoelectronics, temperature measurement
Słowa kluczowe: diody elektroluminescencyjne, LED, optoelektronika, pomiar temperatury

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Introduction

Technological advance caused that luminaries based on LEDs are more and more efficiently replacing traditional solutions in the lighting, based on incandescent bulbs or discharge lamps. New technologies applied in LED diodes provide continual increase of their parameters and boost their application area. When compared with traditional bulbs, LED emitters prove matchlessly long life expectancy. The producers of popular diodes declare useful operation time of their products at the level of 50 000 hours. It means that after this time, the value of emitted light will be higher than 70% of the initial light output through a new diode. Apart from high life expectancy, LED diodes prove very low operation failure frequency. The vast majority of them prove nearly linear decrease of obsolescence over time, caused by the gradual degradation of the semiconductor layers. Thanks to it, their work can be predictable to a large extent and that is extremely appreciated in industrial or professional applications. An unquestionable advantage of diodes is the flexibility of shaping their output colour, thanks to which it is possible to gain white light of a very high colour rendering index (CRI) reminding sunlight which is pleasantly received by the user. Additionally, manipulating the length of the emitted wave enables to gain any monochromatic colour and to limit infrared radiation (IR) and nearly eliminate ultraviolet radiation (UV) which is harmful for living organisms. It opened new possibilities for designers of luminaires since now they can create projects which would be unfeasible using traditional bulbs because of numerous limitations. Another feature thanks to which LED diodes are currently so appreciated in the lighting technique is their high luminous efficiency. Diodes efficiency which exceeds 50% in commercial products causes that a considerable part of the energy absorbed from the grid is emitted back to environment in the form of visible radiation and its smaller part gets there in the form of infrared radiation – heat. The luminous efficiency of LED diodes exceeds 100lm/W. In practice it means obtaining tenfold amount of light using up the same amount of energy as incandescent bulbs. Mentioned pros are only some of the characteristics making LED diodes more and more popular. Yet, the technology does not lack disadvantages. Sizeable sensitivity to temperature belongs to the biggest problems of diodes as well as of most semiconductors. Providing described parameters requires maintaining the diodes operation temperature at a secure level. Exceeding the values declared by the producer in the catalogue notes triggers the change of optical and electrical parameters and the significant shortening of their life expectancy.

Managing heat in LED diodes

Each body whose temperature is higher than 0K (absolute zero) emits thermal radiation – heat – in a form of electromagnetic waves from the infrared scope that is 0,1 μm to 100 μm. Energy measure of such radiation is temperature. According to the producers' recommendations, the scope of operation temperatures of most of LEDs offered on the market ranges from -40 to 125°C. High diodes efficiency is connected with low infrared radiation. Single LED used in the lighting are characterized with power of from 0,5 to 5W. In comparison to some of the semiconductor power elements, dissipating such an amount of energy does not seem to be a problem. Still, it has to be remembered that presently produced diodes are of very small dimensions. The production standard of popular diodes made in SMT technology are elements having the dimensions 3,5mm x 3,5mm. Replacing plastic cover with ceramics of high thermal conductivity makes it possible to control such diodes with high current, obtaining power amounting up to 5W [1]. It causes creating large power density on a small surface and that fosters immediate temperature increases. If the efficiency of the described diode is 50% then the surface power density is at the level of 20W/cm^2. Only providing efficient conditions for heat abstraction guarantees gaining parameters at the described level and maintaining the values during the whole period of diodes usage. Frequent dissipating of such an amount of energy requires using additional heat abstraction systems in the form of radiators. In the most of high power LEDs (power higher than 1W) there is factory mounting a heat sink in the form of MCPCB board in star type. However, higher power LEDs require additional cooling system. Popular heat sinks used to cool LEDs are presented in the picture no.1.

Efficient heat dissipation often constitutes a problem for luminaires constructors. The necessity of using outside large-surface radiators enlarges the dimension of the whole luminaire, restricting some of the diodes uses. Moreover, ribbed radiators built of aluminum sheet metal in some cases worsen the aesthetic values of the whole lamp. The luminaires of popular LED lamps, being the substitutes of traditional bulbs, use their cover, enlarging its surface, so that they remind popular bulbs and do not diverge from conventionally accepted standard recognizable for users (fig.2).

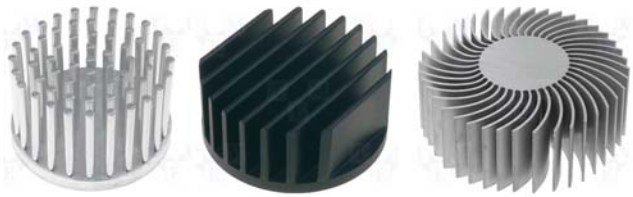

Fig.1 The examples of heat sinks used to cool LED diodes [2]

Fig.2 LED lamps constituting the substitutes of traditional bulbs

Limiting the light flux and luminous efficiency under the temperature influence

Out of the principle of diodes operation it results that reducing the blocking barrier on the border of P and N layers takes place together with the increase of the forward voltage and that causes boosting the conduct current flowing through the diode. Most of the energy carriers undergoing radiative recombination causes releasing more photons. For that reason, the increase of the current flowing through the diode causes the increase of the diode light flux. Higher radiation energy causes the temperature increase of the P – N connector. Long-lasting working of increased operation temperature of diodes finally affects weakening optical parameters and decreasing luminous energy emitted from LED diodes. It is a basic problem of such a kind of light sources. The results of long-term research published by the producers of diodes (fig.3) unequivocally indicate at lowering the light flux of diodes under the influence of high temperatures operation for a long period of time. The reason for such a phenomenon is faster degradation of the semiconductor structure causing its early defect. It has to be also noted that under the temporary working of bigger current and the increase of light flux there follows the decrease of luminous efficiency. The popular 1W SMD 5152 series diodes, whose nominal driving current is 300mA proves the biggest luminous efficiency of 148 lm/W for the current of 100mA. For 450mA so for the maximum allowable current value, the luminous efficiency decreases to 117 lm/W [3]. Such data firmly show that choosing appropriate operation temperature of diodes is crucial in order to maintain the light flux at the required level depending on the purpose. The procedure applied by the producers of low-quality diodes is publishing the value of luminous efficiency of their products for the current lower than nominal with the aim of achieving better results. Such activities are permissible but they indirectly mislead the potential buyer.

The influence of heat on the radiation spectrum

The change of quality and colour of emitted light has to be mentioned apart from the influence of the temperature on the whole radiation power emitted by diodes. Setting the spectral distribution enables examining the content of particular component colours in the whole radiation spectrum. Gained results serve also to compute the colour rendering index and colour temperature of the examined light source. On the basis of spectrum, it is possible to determine trichromatic coordinate on the chromaticity chart CIE1931. Thanks to that, one gets the picture of monochromatic colours in the examined light in a way easier to study for the user than the spectral distribution. Research results of the 4W warm white diodes, are depicted in the picture no.4. Conducted research proved the change in the radiation spectral distribution under the influence of high temperatures. As a result of semiconducting structures overheating, there follows the change of the component waves content. The results of the measurements prove decreasing the value of location on the CIE1931 chart on both X and Y axes. It means changing emitted colour and bigger content of components responsible for blue and violet colours [4]. Such a phenomenon is visible in the LED lamps of low quality in whose production many single emitters of medium power were used.

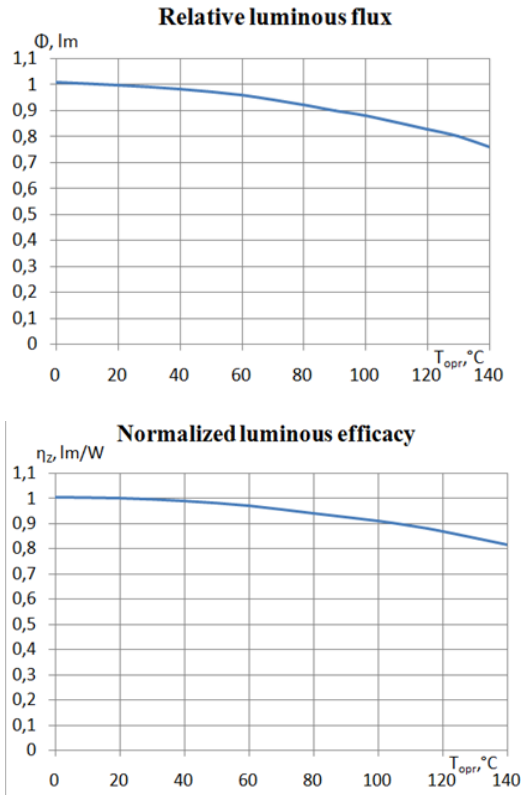

Fig.3 The decrease of optical parameters under the influence of operating at a higher temperature of one of popular high power LEDs

Diodes used in such a kind of lamps are often driven by the current exceeding their safe value, and cooling conditions are not provided in an efficient way. After many working hours some of diodes change their colour into the one reminding violet. This phenomenon can be observed in such lamps since in direct neighborhood of the destroyed diode there are other emitters which can serve are a reference sources to compare colours. The chart showing the result location change on the chromaticity chart under the influence of temperatures is presented in the picture no.5

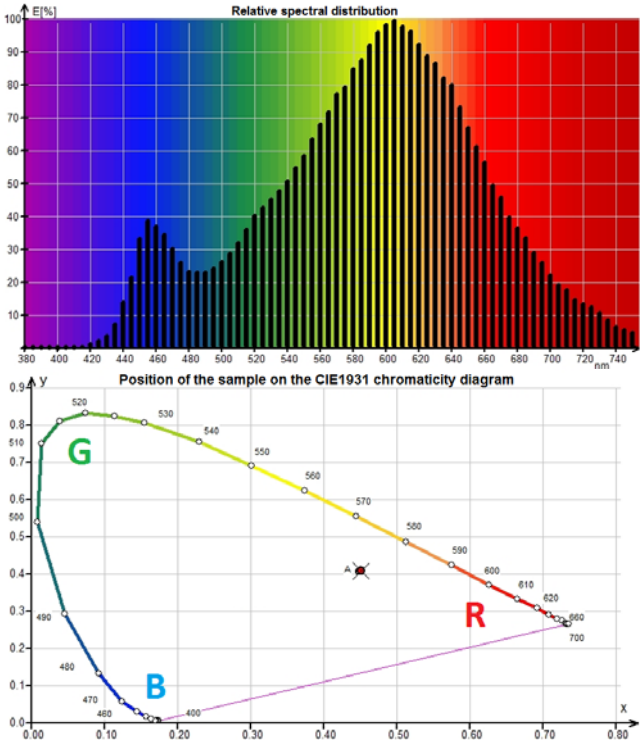

Fig.4. The presentation of the measurement results of the 4W warm white diode: a) relative spectral distribution; b) chart CIE1931

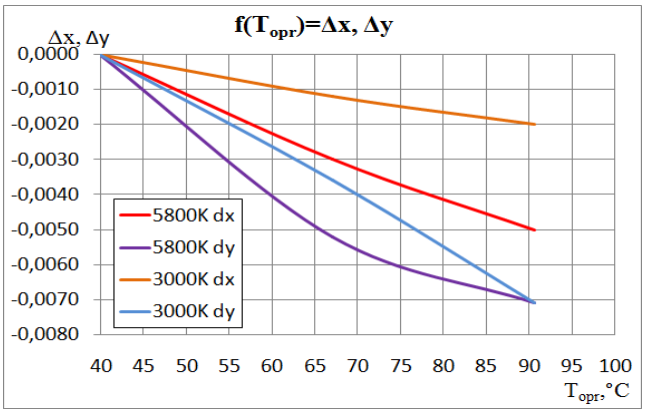

Fig.5. Trichromatic coordinates change of the 3W warm white and cool white diodes under the influence of a temperature.

Electrical parameters

The influence of heat on LEDs performance can be observed not only within the range of optical parameters. Too high temperature affects electrical properties of diodes as well. Such elements are characterized with negative coefficient of temperature voltage decrease. It means that under the influence of higher operation temperature, the diodes forward voltage decreases and the square of the current flowing through the diode increases. The effect of such a phenomenon is increased diode consumption of power. It is a very dangerous appearance. It can be caused by the existence of other light sources near diodes or temperature increase of the works neighborhood. This process may turn out to be a threat especially to the elements which are driven with maximum admissible current properties during their working time; then increasing their power leads to exceeding permissible operation temperatures. The right construction of luminaires should predict extreme conditions which may arise in the course of using diodes and contain some margin for additional power caused by a described effect. It is realized through decreasing the diodes operational current (directly gaining higher luminous efficiency) or through using bigger heat sinks. Devices operating LEDs which are currently offered on the market – power supplies or drivers – are equipped with temperature sensors and systems compensating temperature influence, properly adjusting the current delivered to the semiconductor. The impact of the temperature on the diodes forward voltage is presented in the picture no.6.

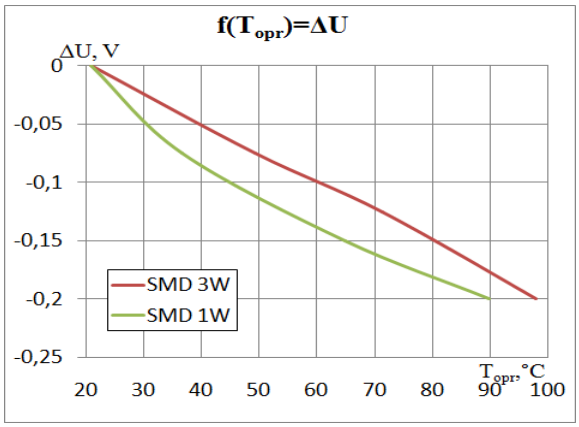

Fig.6 The relationship of forward voltage decrease versus operation temperature of popular 1W and 3W SMD diodes.

The decrease of diodes life expectancy under the overheating influence

A very long time of diodes operation constitutes a basic argument used by producers from LED industry to advertise their products. However, such an asset becomes leveled by inappropriate diodes usage. In the catalogue notes there is abundant information concerning the way of their storage and service. Wrong temperature and humidity of both operation and storage cause considerable diodes life expectancy decrease. Their failure frequency, triggered by early, total failure, increases. LED diodes (especially SMD) operating instructions contain also information on time and temperatures of soldering. Appropriate and compatible with recommendations diodes fixing requires using machines to SMT assembly such as pick&place automatons or multi-level soaking ovens. Such conditions are frequently difficult to copy at home. It has to be also remembered that by the transport or assembly of diodes it is necessary to use tweezers – most preferably made in the ESD standard. Direct touching of diodes phosphor surface may lead to shortening their obsolescence. Diodes producers conduct long-term research and simulations on the basis of which they publish the predicted time of diodes lighting in a given temperature of the connector. Major LEDs manufacturers preparing algorithms to estimate diodes obsolescence. The chart in the picture no.7 presents the results of long-term research of a high power LED.

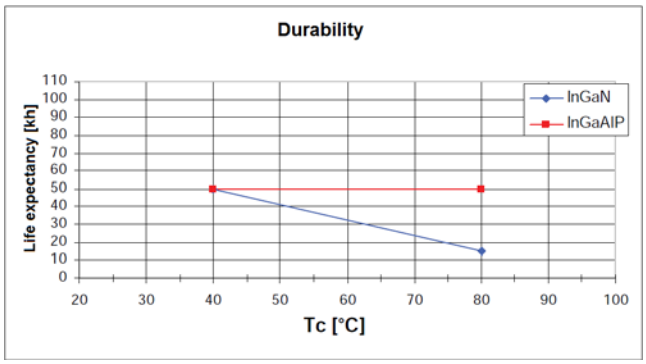

Fig.7 The dependence of life expectancy of high power LED on the case temperature [5]

Cooling choice

In order to maintain uniform value of light flux, colour representation durability and predicted diodes life expectancy, it is necessary to apply proper heat dissipation system. LEDs of medium and high power are recommended to be turned on only after placing on MCPCB boards of a star-type allocated to them which dissipate heat released by the semiconductor. Such information is included in majority of datasheets provided by the diodes producers. However, during the long-term operation such a solution may be insufficient and it is necessary to use additional cooling systems. The thermal resistance is calculated on the basis of thermal conductivity of the material the heat sink is made of and its surface. Such a value defines the pace of heat flow between two systems. A good procedure to improve such a parameter is using thermal grease which provides permanent connection between the MCPCB and the diode with the additional radiator. The procedure allows to reduce the thermal resistance between these two surfaces from 2 K/W to circa 0,1 K/W [6]. A standard star heat sink is a sufficient solution to cool diodes whose power does not exceed 1W. However, the test results of the diode, whose power reaches up to 3W, prove that in order to cool the diode it is necessary to apply the additional radiator in a form of a flat aluminum wafer attached to the MCPCB star with the diode (fig.8b). In practice, depending on the application, it can be replaced with aluminum moulding on which the diodes are placed or some other element using the cover of the diode luminaire. In case of testing the diodes, whose power exceeds 4W, the flat wafers reached the temperature higher than 100°. Their application is not a sufficient solution for the long-term diode operation.

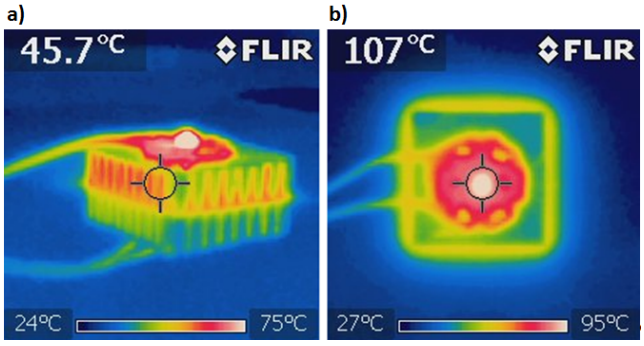

Fig.8 The results of research with popular SMD diodes thermographic camera: a) 4W 5152 LED on ribbed heat sink; b) 3W 3535 ceramic LED on flat aluminum wafer

A ribbed heat sink also made of aluminum (fig.8a), whose surface of heat abstraction is considerably bigger, would be a much better solution here.

Proper cooling conditions of such a kind of diodes need adjusting the cover of a luminaire, replacing some of its elements made of plastic with ceramic or aluminum material.

Summary

LEDs surely posses many advantages thanks to which they play more and more important role on the lighting market. Despite their high mechanical strength in comparison with traditional bulbs containing glass shell, sensitivity of the semiconductor structure of diodes to temperature changes causes worsening optical parameters and shortening the life expectancy of diodes themselves in case of their overheating. The loss of a part of light flux causing worsening luminous efficiency influences lowering popular benchmark used by marketing specialists – energy efficiency. Easiness in driving diodes cannot be used when, at the moment of overheating, the location of the diode on the CIE1931 chart changes; the result of it is colour temperature and colour rendering index change. The necessity of using heat sinks dissipating heat can negatively influence the luminaire aesthetics. However, on the other hand, it improves usage security since while dissipating heat with their whole surface, the heat sinks do not reach the temperature which may worsen the comfort of their usage. Instructions on how to use diodes, published in datasheets, are not emphasized by the producers in the same way as optical parameters performance. Constantly developing technology and greater and greater competition in the LED industry leads to decrease of prices of such a type of luminaires. In spite of this, diodes prices still exceed the cost of luminaires built on the basis of traditional light sources. Therefore, in order to prove their competitiveness, the optical parameters of LED diodes have to serve as their strengths. Providing proper operation conditions, LED diodes offer incomparably bigger possibilities than the ones of traditional lighting. Thanks to that, the light extracted out of semiconductors for quite a long time is commonly called “the lighting technology of the future”.

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