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THE INFLUENCE OF ASSEMBLY TECHNOLOGY ON EXPLOITATION PARAMETERS OF POWER SSL-LEDs

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The SSL-LEDs (*Solid State Lighting* LEDs), often of several watts consumed unit power are generally fixed to a cooling substrate to increase the on LEDs' durability, reliability and light efficiency. The size, shape, cooling area and ventilating properties of the substrate, made mainly of aluminum or copper, have to be taken into account. The next problem is the thermal resistance minimizing between the LEDs body and the substrate. Here the out growth is the choice of a LEDs fixing method. The work deals with six fixing methods and reports their properties, achieved by reducing the thermal resistance between LED and the radiator's substrate. The first method consists in purely mechanical fixing by screws. The second is completed by a silicon film. The third one utilizes a foil of excellent thermal resistivity, covered on both sides with an acrylic glue. The fourth simple method bases solely on of an acrylic glue. The fifth method consists in using a resin with aluminum powder and cured at room temperature. The last method makes use of a special silicon CAF-1 type glue. In all cases identical LEDs, radiators and applied powers were used and results compared.

Keywords: power SSL-LED, assembly technology, exploitation parameters, thermal resistance

1. INTRODUCTION

The contemporary mass use of LEDs, especially of high power sometimes reaching 10 Watts or more – extorts some special measures enabling efficient cooling

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of these light sources. The cooling process exerts a significant positive influence on LEDs light intensity and durability, so all the accompanying methods and circumstances ought to be well known, properly realized in practice and propagated. Besides the obvious effects, created by radiators of various sizes and shapes – some crucial factors are influencing the minimization of thermal resistance between the LED and radiator, as well as sureness of mutual fixing. This in turn influences the costs of the entire light source's assembly, especially when lots of LEDs have to be mounted. It's evident, that the objects of these presented considerations are solely power LEDs, equipped with own cooling flat elements, acting as a main heat off take while cooperating with a radiator's surface.

Among factors to be discussed are the means and methods of minimizing the thermal resistance, the ways of effective mutual fixing LEDs and radiators, the dimensions and shapes of these last ones from the point of view of heat distribution, as well as eventually problems of natural and artificial cooling processes.

2. THEORETICAL AND PRACTICAL REMARKS ON LEDs COOLING

Contemporary LEDs of high brightness are replacing more and more traditional light sources like tungsten bulbs, fluorescent lamps and halogene ones. They single out by high light efficiency, reaching 30 %, very long life time, the lack of sudden failures, lack of infrared radiation and by safe powering voltage level of only several volts (Tab. 1 [1]).

Table 1. List of significant light sources parameters.
Tabela 1. Zestaw ważniejszych parametrów źródeł światła.

	100 W tungsten bulb	fluorescent lamp	halogen	white colour LED
Visible light region	5%	21%	27%	15-30%
Infrared	83%	37%	17%	0%
Ultra-violet	0%	0%	19%	0%
Total radiated light energy	88%	58%	63%	15-30%
Heat energy	12%	42%	37%	70-85%
Altogether	100%	100%	100%	100%

Modern technologies enable to obtain high luminance values per junction surface unit, as well as per electric power applied, e.g. even 115 lm/W. For satisfactory performance – however – the junction temperature has to be kept as low as possible to dissipate the waste heat energy level, reaching 85 % of that delivered. As the peak LED junction temperature levels must not exceed 150°C – the optimum long-term values should be as high as 60-80°C. The harmful temperature influence on LEDs luminosity and durability is shown on Figs. 1. and 2.

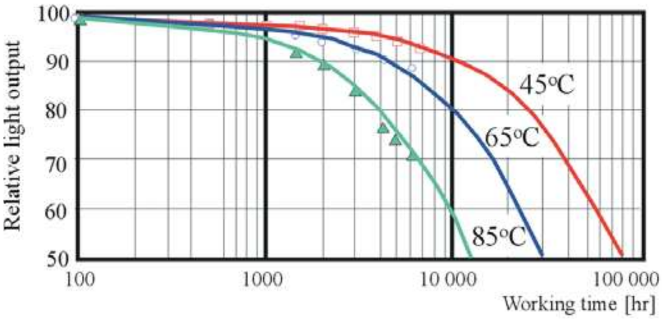

Fig. 1. The influence of LED's temperature on luminosity and durability [2].
Rys. 1. Wpływ temperatury na jasność i trwałość LED-ów [2].

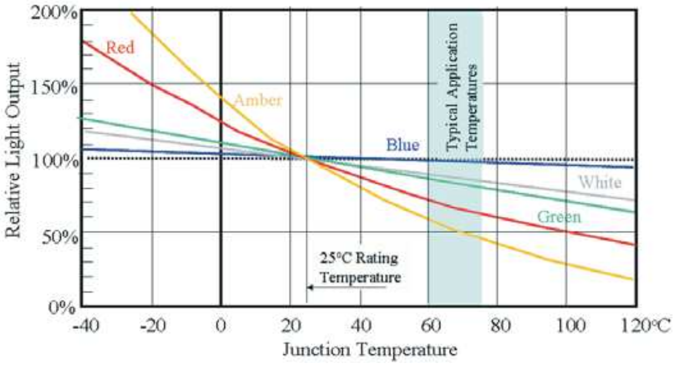

Fig. 2. The influence of LED's junction temperature on the light output with dependence on light colour [3].
Rys. 2. Wpływ temperatury złącza LED-ów na wydajność światła w zależności od koloru [3].

The LED lighting system (Fig.3.) has to be connected firmly to a radiator by one of several existing methods, enabling durable mechanical fixing, as well as the possibly most efficient thermal contact between the system and the radiator.

As the last one a 70 mm square aluminum blackened profile of Fig. 4. was chosen for further experiments.

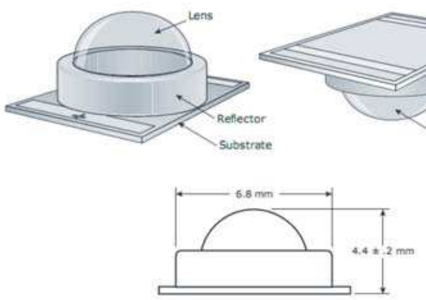

Fig. 3. Exemplary view a 3W LED system with its substrate and contacts [4].
Rys.3 . Przykładowy widok diody LED 3 W z podłożem i wyprowadzeniami [4].

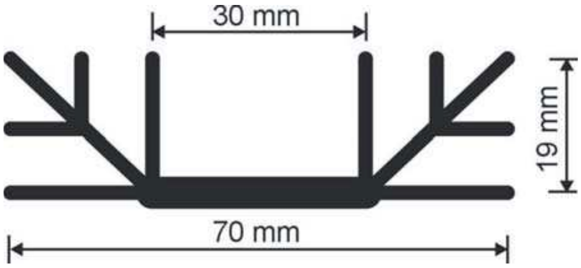

Fig.4. The shape and dimensions of the chosen radiator.
Rys.4. Kształt i wymiary obranego radiatora.

The entire assembly, created by LED, radiator and other elements presented on Fig. 5. – performs the distribution of thermal resistances of this assembly. The best valuation criterion of the so constructed model is the lowest thermal resistance of the path of the main heat stream, running through the p-n junction to the outer radiator's surface [5].

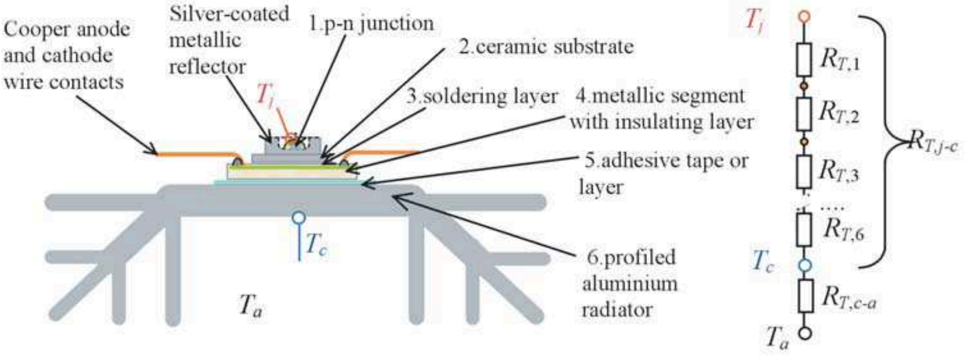

Fig. 5. Distribution of thermal resistances between ambient and junction.
Rys. 5. Rozkład rezystancji termicznych między złączem a otoczeniem.

For a stationary heat stream of power P it may be defined as:

$$R_{T,j-c} = \frac{T_j - T_c}{P}$$

where: T_j – temperature of p-n junction, T_c – temperature of the radiator's outer surface, $P = U_F \cdot I_F$ – power dissipated by the diode.

It's an additive value, consisting of thermal resistances of all individual elements and adhesive layers (assuming P = const), resistances defined by thermal conductivity coefficient k_i, by thickness d_i of each element and layer on route of the heat stream and by the surface of the stream's cross-section S_i inside the i^{th} element (or layer):

$$R_{T,j-c} = \sum_{i=1}^{N} \frac{d_i}{k_i S_i}$$

As k_i and d_i are dimensioned by the sort of material and by thickness – the S_i value varies in each element with the distance to the heat source. The precise numerative analyzes base on Fourier equation's solution for thermal conductivity with defined boundary conditions. In practice usually approximated calculations are carried on for the heat stream spreading at an angle 45° in each next layer of surface much greater, than the former one and of much higher k coefficient value. Such a model admits isothermal features of the contact between the metallic element with the ceramic substrate. The metal cores in this model widen the surface of the heat stream surface in worse conducting sequential constructional layer and joints. Basing on the above assumptions – the entire light module's thermal resistance has been evaluated, as in Tab. 2 below.

Table 2. An evaluated balance of thermal resistances in an exemplary model of Fig. 5.
Tabela 2. Szacunkowy bilans rezystancji termicznych w przykładowym modelu z Rys. 5.

No.	Element	k_i [W/mmK]	d_i [mm]	S_i [mm^2]	$R_{T,i}$ [K/W]
1	GaN semiconductor layer	0,13	0,2	2,0x2,0	0,385
2a	Sapphire 40W/mK	0,04	0,4	2,4x2,4	1,736
3	Au-Sn solder	0,225	0,1	2,5x2,5	0,711
4	Cu Metal-core PCB	0,38	2,0	$\pi 10^2$	0,024
5a	The LOCTITE glue layer	0,000815	0,25	$\pi 10{,}25^2$	0,93
6	Al radiator	0,21	4,0	$\pi 14{,}25^2$	0,03
Altogether with 2a variant					3,816
2b	AlN Ceramics	0,15	0,4	2,4x2,4	0,463
Altogether with 2b variant					2,543
5b	HVB adhesive tape		0,25		

The outer radiator's temperature T_c depends in turn on the mechanism effectiveness of thermal convection towards the ambient, i.e. the air of an average T_a temperature. The thermal resistance between the radiator's horizontal surface S and the air may be defined as:

$$R_{T,c-a} = \frac{T_c - T_a}{P} = \frac{1}{\alpha_{con\neg} S}$$

where: $\alpha_{con\neg}$ [W/m^{2}K] is the convection coefficient of the cooling medium. At upward heat convection it may be admitted, that $\alpha_{\mathrm{con}\neg\uparrow} = 2,5(T_c\text{-}T_a)^{1/4}$, while at downward direction $\alpha_{\mathrm{con}\neg\downarrow} = 1,3(T_c\text{-}T_a)^{1/4}$, though still many factors, such as air humidity, influences this coefficient.

Normally, at the fixed P, the LED's user may influence only the thermal resistance of glue or paste and that of the air-cooled radiator.

3. EXPERIMENTAL

Initially as the basic condition six pieces of 3 W LEDs (Fig.3.) and of strictly the same voltage drop at the same current – have been chosen from a lot of pieces being in disposal. This means the same power consumption of all the LED's used.

As the radiator a blackened aluminum profile of cross-section shown on Fig.4. was selected and six separate and identical 70 mm cuttings were prepared. Only two of them were equipped with a pair of holes for fixing the LEDs by means of screws, while the remaining four assemblies were provided to use various types of tested gluing techniques. In all cases LEDs will be placed centrally.

The goal of all these intentions was to compare five various fixing solutions with the first basic one, which consisted in conventional thermal contact by means of ordinary screwing.

For the mutually compared five cases dealing with fixing and heat conduction improving or simplifying methods – the most popular and recommended ways and mediums have been employed. Thus as the naturally basic comparative method a simple mechanical fixing by two screws was acknowledged, though the solution is certainly not the easiest way of fixing LEDs in mass manufacturing scale.

All the tested radiators equipped with LEDs connected in series and thus of the same flowing currents – were placed in a room temperature of 25°C for one hour with the same cooling conditions. After one hour of heating – the temperatures of LED junctions T_j as well as of the same point on each radiator T_c have been measured and reported in Tab. 3. At the same time a foto from an infra-red camera has been prepared (Fig. 6.), where accidentally the 6 separate samples are not situated in the sequential order like in the Tab. 3., but only placed tightly for photo lens purposes.

Table 3. The LED's junction and radiator temperature in dependency on ways of fixing.
Tabela 3. Temperatury złączy LED-ów i radiatorów w zależności od sposobów mocowania.

Type of test Tested element nr.	T_j [°C]	T_c [°C]
Two screws fixing 1	45,46	38,13
Two screws fixing plus silicon paste 2	42,47	36,36
Double layer adhesive tape 3	47,88	36,36
Acrylic glue 4	40,88	36,97
Epoxy resin 5	43,16	37,34
CAF-1 silicon glue 6	43,08	36,60

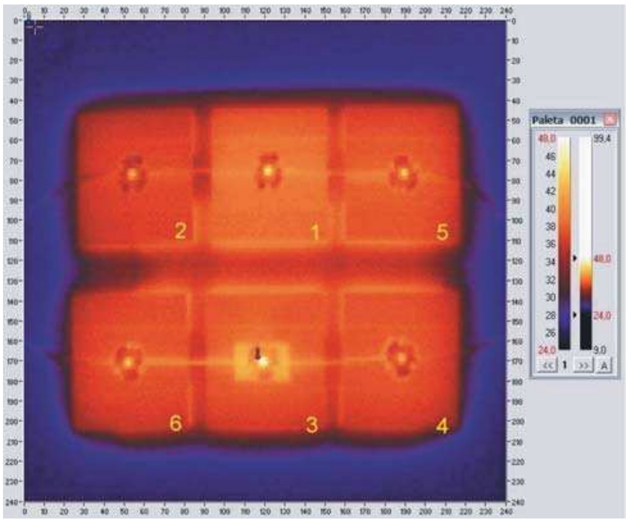

Fig. 6. Distribution of thermal resistances between ambient and junction (I-R photo of six separate radiator samples equipped with LED's, placed close to each other, taken after one hour powering).
Rys. 6. Rozkład rezystancji termicznych między otoczeniem a złączami (fotografia w podczerwieni sześciu radiatorów z osadzonymi LED-ami, umieszczonych blisko siebie, sporządzona po jednogodzinnej eksploatacji).

The intensity of colours also do not precisely show the generally small differences in junctions „and radiators" temperatures. These small differences observed are probably caused as a result of choice of several recommended best mediums, appropriated for such an aim.

The criterion of this choice then ought to be rather the assembly costs, as well as the quality and durability of the sole fixing method. Here also the easiness of accidental removing the failure LED has to be taken into account.

The Tab.3 data are showing no significant differences in radiators' temperature. The evidently worst cases are the third and the comparative first one, without any heat conducting medium inserted. The effect of the lack of such a medium is obvious and is easily reduced by means of several sorts of pastes since many tens of years. All the other four cases seem to be efficient in a similar way, though the thermal resistance of the adhesive tape case is 3 times higher and thus worse, than that of the acrylic glue. In turn the thermal resistance of the Tab. 2 fifth position presents only a partly significant fraction of the summed up resistances. According to test practice – the fixing abilities do not differ significantly, but in necessity of removal a failured LED the reminders of pos.5 and 6 (Tab. 3) glues appear difficult to be cleared. It may be supposed, that more precise temperature differences and heat distribution results in comparison with those from Tab. 3 would be obtained on much smaller radiators, as the dimensions of here applied ones are evidently greater than necessary and thus too expensive in practice.

4. CONCLUSIONS

The carried out tests showed, that five of six presented LED fixing and cooling methods are recommended under certain stipulations. In the domain of cooling support and thermal results all of them are generally almost coordinate. The differences consist in the price of necessary material portion per one LED piece, in technological easiness of implementing this portion, in mechanical features and demands of the glued fixings and at last – in the ease of disconnecting the formerly glued elements if necessary. Quite obvious seems to be the remark, that only the screw fixing system offers the best sureness in vibrating conditions, as well as in situations of high and fast ambient temperature and moisture variations. In turn the screwing is extremely laborious, especially in mass manufacturing processes. A middle way instead of screws might present a spring wire clamp, similar to that used to fix the power transistor to the radiator. All of these premises mentioned ought to be scrupulously taken into account while designing the technology of a definite case.

The superior goal of all the above considerations and efforts is the prolonging of efficient and durable functioning of LEDs, as main light sources of the near future.

5. ACKNOWLEDGMENTS

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WPŁYW TECHNOLOGII MONTAŻU NA PARAMETRY EKSPLOATACYJNE SSL LED-ÓW MOCY

Półprzewodnikowe diody mocy LED bywają mocowane zwykle do chłodzącego podłoża celem zwiększenia ich trwałości, niezawodności i sprawności. Rozmiary, kształt, powierzchnia chłodzenia i własności chłodzące podłoża, wykonanego zwykle z aluminium lub miedzi winny być starannie analizowane. Dalszym problemem jest rezystancja termiczna pomiędzy korpusem diody, a podłożem. Wiąże się ona ze sposobem jej mocowania. Praca omawia sześć metod mocowania i relacjonuje ich wpływ na rezystancję termiczną pomiędzy diodą a podłożem radiatorowym. Metoda pierwsza polega na czysto mechanicznym mocowaniu wkrętami. Druga wprowadza cienką warstewkę silikonu. Metoda trzecia stosuje folię o dobrej przewodności cieplnej, pokrytą obustronnie klejem akrylowym. Czwarta, prosta metoda bazuje wyłącznie na spoiwie akrylowym. Piąta metoda polega na sklejaniu żywicą zmieszaną z pyłem aluminiowym i utwardzaną w temperaturze pokojowej. Metoda szósta wykorzystuje specjalny klej silikonowy typu CAF-1. We wszystkich przypadkach użyto identycznych diod LED, radiatorów i aplikowanych mocy świecenia, a rezultaty prób przedstawiono i skomentowano.

Słowa kluczowe: diody mocy LED, montaż, parametr eksploatacyjny, rezystancja termiczna