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ANALYSIS ON THERMAL BEHAVIOUR OF THE SINK AND DIE AREA WITH DIFFERENT THERMAL INTERFACE MATERIAL FOR HIGH POWER LIGHT EMITTING DIODES

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ABSTRACT

Its self-heating process directly affects the optical performance and reliability of light – emitting diodes (LEDs). It is important to disperse the generated heat from LED to surrounding atmosphere and keep the LED light performances same as declared by the manufacturer. Thermal interface material (TIM) is applied in between sink and source to reduce contact resistance at the junction between substrate and heat sink interface of the LED modules. This paper provides an assessment on 'thermal interface materials'. Here different TIM materials used and the performance and problems of these commercial interface materials are discussed. From this study, one can calculate the temperature distribution in the sink area for different types of TIM materials under thermal conductivity perspective and be able to find the capability of dissipation of heat at the end surfaces of heat sinks, and design their system as well. In another process, TIMs with different thickness and input drive currents for the COB-based LED are investigated by using *COMSOL* simulation software. The results show that the junction temperature of the LED luminaire increases and reduce the lifetime when the input drive current and thickness of the TIM layers increase.

Keywords: heat dissipation capability, heat sink, junction temperature, luminous flux, thermal interface material (TIM), thermal pad

1. INTRODUCTION

The solid state lighting device like light emitting diode (LED) is the most prospective solution for lighting issue in the today's world considering its low power consumption, long lifetime, eco-friendly behaviour and instant-start-up characteristics over the other conventional lighting sources. In this case, the LED luminaires do not provide the rated light output according to the data provided by the manufacturers in actual use. As a solution, many manufacturers are overload the LEDs at high power to provide more light output. Therefore, an experimental study was conducted to investigate the photometric results of white LED as a function of time with different drive currents [1]. As per the feedback from field, it is reported that improper heat dissipation leads to failure of LEDs. Thus, thermal management [2, 3] is essential for the design of LED based luminaires because of its higher junction temperature, which reduces the light output, luminous efficacy, and of course its reliability too [4, 5, 6, 7].

When a higher driving current is applied to LEDs, although light output increases [8] but it is associated with increase in heat generation, energy consumption etc. Light output again decreases with temperature rise at the junction of the LEDs, which is termed as junction temperature. Daren Alfred Lock et al. [9] described the technique for determining the junction temperature using generated photocurrent within the device. Quan Chen et al. [10] proposed a system for measuring the dynamic junction temperature for LEDs with the calibration including instrument calibration and factor K calibration. They analysed influence of the fast time switching in dynamic junction temperature test and quantified measurement errors caused by sampling delay. They also conducted a comparative experiment to prove the accuracy of the present system, which shows a good agreement between the experimental data and reference value. Chi-Yuan Lee et al. [11] fabricated a flexible micro resistive temperature sensor to measure the junction temperature of LED, and the junction temperature of the LED can be measured from the linear relationship between the temperature and the resistance. Minseok Ha et al. [12] implemented an analytical thermal resistance model for high-power LED packages of chip-on-board (COB) architecture combined with a power electronic substrate and validated by comparing it with finite element analysis (FEA) results, which allows us to understand the impact of design parameters (e.g., material properties, LED spacing, substrate thickness, etc.) on the packaging thermal resistance. A.E. Chernyakov et al. [13] studied of the current crowding effect on the LED thermal resistance and its variation with the driving current. They had been studied current spreading in a high-power flip-chip LED and its effect on the chip thermal resistance both theoretically and experimentally. Kai Han et al. [14] used different measurement currents to estimate the junction temperature of high-brightness LED at a sampling rate of 1 MHz.

In this study, temperature distributions at the package level and the high power LED- array system had been investigated using numerical models of heat flows and a network model of thermal resistors in combination with a 3D finite element sub model of an LED structure for predicting the system and die level temperatures. This makes it easier to calculate the effect of the LED array density, LED power density, and the method of active and passive cooling during operation of the device [15]. Direct measurements of LED junction temperature are difficult. An alternative method had been developed using current-voltage characteristics of commercial high power LEDs. The same has been used for measurement at six different temperatures in the range from 295 K to 400 K [16]. Comparison of the thermal parameters of various substrates, such as standard glass epoxy substrate (*FR*4) and insulated metal substrate (IMS) for high power LEDs, has been made with an emphasis on cost and size [17]. A deeper understanding of the thermal behaviour of an LED module could be gained by in-depth analysis of the thermal path during operation of the device [18]. LED failure factors are one of the big issues, which are the challenge to find out and solve the said problems. The main failure modes, such as bonding defects, die attaching defects, and other defects caused by poor packaging process, are investigated using some failure analysis cases [19]. Using experiments and numerical analysis, high power LED modules encapsulated with different lens shapes and size after thermal-aging test were studied [20].

Although the claimed lifetime of LEDs is very high, but in tropical countries their lifetime appears very short. Thus, experimentation were conducted using various types of commercially available high power LEDs and in various major locations, e.g. die and sink areas, the test results have been presented here after [21]. Humidity and high temperature are used as accelerating variables, especially for destruction mechanisms associated with optical degradation [22]. In this paper, three different types of thermal interface materials (TIM) with different thermal conductivity were used for the experiment. The main role of TIM materials is to eliminate air gaps or spaces (which act as thermal insulator) from the interface area in order to maximize heat transfer. End surface temperature of the heat sink were measured at intervals up to one-hour and the results were analysed. Another simulation was performed of the COB-based LEDs with different drive currents, as well as thickness of the TIM layer, and the simulation results were investigated.

This paper presents a method for conducting experiments and analysing test data (the temperature of the end surface of the heat sink), as well as a new formula for calculating the junction temperature of LEDs, which could not be measured directly. In addition, an empirical formula has been developed, by which the area of trailing surface of the heat sink can be estimated or calculated based on different operating time. The driver current and the thickness of the LED's TIM layer increase, which raises the junction temperature and reduces its lifetime.

2. LUMINAIRES AND THERMAL INTERFACE MATERIALS SELECTION

This experiment involves ten luminaires, each of which is a commercial downlight type luminaire based on modules SMD (a) and COB (b) with the

Table 1. Luminaires Specifications

LED luminaire	Power	Input current (DC)	Input voltage (DC)	CCT	Dimensions (D×H)	Material
COB-based Cool White	5 W	300 mA	18 V	6500 K	D=75 mm H=22 mm	aluminium alloy
SMD-based Cool White	5 W	300 mA	18 V	6500 K	D=90 mm H=55 mm	aluminium alloy

Table 2. Thermal Interface Materials Specifications

Material name	Thermal conductivity (W/mK)	Typical thickness (mm)
Type 1: thermal paste	0.50	0.0825
Type 2: non-silicone thermal pastes	0.72	0.0825
Type 3: thermal insulator pads	0.90	0.1

same structures as shown in Fig. 1. Two different types of thermal interface materials (TIM) are imported in a different way than provided by the manufacturer. The list of LED modules and material specifications are given below in Table 1 and Table 2, respectively. The heat sink is made of aluminium alloy and surrounds the back of the LED luminaire housing. The typical driver is an external part to LED luminaires**.**

3. METHODOLOGY ADOPTED

3.1. Luminous Flux and Sink Area Temperature Measurement Process of LEDs

In this part of the experiment, selected commercial led lights (both SMD and COB modules) provided by the manufacturer are placed inside the integrating sphere one by one to measure photometric and electrical parameters. The temperature around the luminaire in the integrating sphere is set at room temperature (25 °C). Each LED luminaire is allowed to keep in thermal equilibrium at this temperature, which takes about 45 minutes, and then the luminaire turns on in the nominal mode. Then the stabilization time of a LED luminaire at power-ON condition in the sphere was taken 30 minutes for each case. Then photometric parameters, i.e. luminous flux of the luminaire, are measured according to Indian standards (IS:16106,2012). Electrical and photometric measurements of the luminaires were carried out according to recommended method of IESNA LM-79, designed for electrical and photometric measurements of *SSL* (LED) products. The next step is to measure the surface temperature of the end position of the LED heat sink. For this measurement, an enclosure box made by plywood with a dimension of (350 mm×350 mm×350 mm) was used, and the temperature inside the box was set at (25–27) °C as determined by Joint Electron Device Engineering Council (JEDEC) [23]. Then each LED module was mounted horizontally in the geometric centre of the box, and a non-contact calibrated infrared (IR) camera (Fluke make *Ti* 400) was fixed at a distance of half a meter from the end surface of the heat sink. The temperature measurement of end surface of the sink is recoded at initial condition of the luminaires power-ON condition and carried forward it after every five minutes interval up to one hour. For these cases, TIM materials of all LEDs match the thermal paste provided by the manufacturer (type 1, thermal conductivity of 0.50 W/mK). During IR thermographic measurements, the humidity inside the box was 45 %.

Fig. 1. The selected LED luminaires with external drivers

Then the TIM material normally provided by the manufacturer was removed, and after that a new non-silicone TIM material, such as thermal paste (type 2), whose thermal conductivity is higher (0.72 W/mK), is placed between the substrate and the heat sink. The above experimental procedures were repeated for each LED module. After that, similarly, the higher heat conducting, i.e. non-sili-

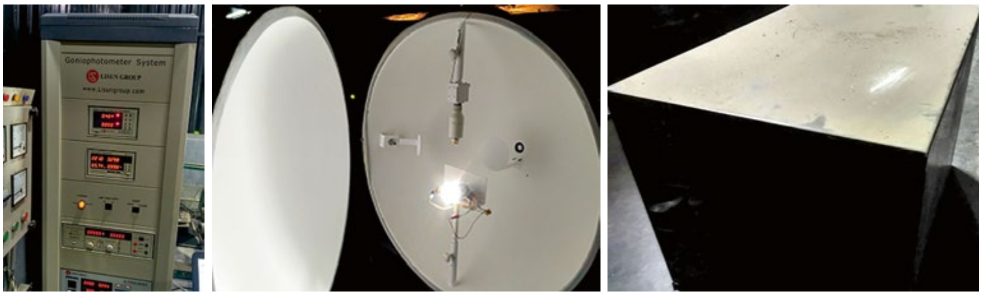


Fig. 2. Experimental setup

cone TIM material was replaced with a thermal insulation pad (type 3), taking the appropriate cleaning process. Then the corresponding measurements of photometric and thermal parameters were made.

All of the above measurements were repeated for 10 times for all the methods, and average values were used in all calculations and graphical plots presented below.

Photometric parameters, such as the luminous flux of both types of COB and SMD-based LED luminaires, were measured using goniophotometric system (photometric integrator, diameter of 1.0 m). Colorimeter type Konic Minolta, model CL 200A, was used as a photodetector. The temperature around the luminaires at the time of measurements should be kept almost at 25 °C. An additional thermometer was used for this condition in the sphere. The Fluke make infrared thermal imager (*Ti* 400) was used to measure temperature using a thermal imager on the surface of the heat sink area. The thermal sensitivity of the *Ti* 400 was ≤ 0.05 °C at 30 °C. The driver output in DC voltage and current were measured at the point where the driver was connected to the LED module. In this study, all the LED luminaires were powered by a current of 300 mA. The experimental setup is shown in Fig. 2.

3.2. Simulated Model of COB-based LED Module

According to the selected COB, a 5 W LED was selected. The overall dimensions of the radiator board are 75 mm in diameter and 22 mm in height, and the material of the sink is aluminium. The chip becomes a heat source during the thermal simulation and has a diameter of 2 mm and height of 0.1 mm. The 3-D model of the LED luminaire is established by *COMSOL* software. The LED chip was connected with the heat sink by type 1 (thermal paste conventionally used by manufacturer – 0.50 W/mK), type 2 (proposed thermal paste – 0.72 W/mK) and type 3 (proposed thermal pad – 0.90 W/mK) TIM materials, one by one. The initial thickness of the type 1 and type 2 TIM materials are 0.0825 mm. However, the thickness of the type 3 TIM material is 0.1 mm. The mesh is applied in the COB-based LED model with all TIM condition. Now the drive current of the LED luminaires are selected as 80 mA, 130 mA, 180 mA, 230 mA, 300 mA, respectively, where the input voltage of the diode is 18 V (DC). Accordingly, the input power of the LED for said drive current is set as 1.44 W, 2.34 W, 3.24 W, 4.14 W, and 5.4 W, respectively. Now in terms of the efficiency of the LED, it is assumed that 80 % of the input power is equal to the thermal power. Therefore, the heat generation rates at *COMSOL* platform are set as follows: (0.92×10^9) W/m^3, (1.49×10^9) W/m^3, (2×10^9) W/m^3, (2.63×10^9) W/m^3, and (3.4×10^9) W/m^3, respectively. For these simulations boundary heating conditions were met on all surfaces of the designed LED module at a given ambient temperature of 27 °C, i.e. 300 K.

Now, type 2 and type 3 materials are selected for further modelling. The thickness of each material is set to double, i.e. 0.165 mm (type 2) and 0.2 mm (type 3). After that, all the condition of the *COMSOL* platform are kept the same as the above process, and simulations are performed to find the required parameters.

4. RESULTS AND ANALYSIS

4.1. Temperature Distribution at Sink Area of the LED Luminaires with Different Types of TIMs

Optical parameters were measured by placing various TIM materials between substrate and sink for two types of LED modules. Here in this experiment, three types of thermal interface material (TIM) were used between substrate and sink with different thermal conductivity, which is shown in Table 2. In each of the cases, the lumen outputs of

Table 3. Luminous Flux for Various TIM Materials between LED Substrate and Heat Sink

TIM materials —’	**Type 1: thermal paste**	**Type 2: thermal paste**	**Type 3: thermal pad**
Thermal conductivity —’	0.50 W/mK	0.72 W/mK	0.90 W/mK
Luminaire types ↓	**Average luminous flux (lm)** ↓		
COB-based 5 W LED	493.90	513.70	521.25
SMD-based 5 W LED	392.00	412.40	435.76

Table 4. Average Temperature at the End Surface of the Sink Area for Three Types of TIM

LED type	**COB-based 5 W LED luminaire**			**SMD-based 5 W LED luminaire**		
TIM material	Type 1: thermal paste	Type 2: thermal paste	Type 3: thermal pad	Type 1: thermal paste	Type 2: thermal paste	Type 3: thermal pad
Thermal conductivity	0.50 W/mK	0.72 W/mK	0.90 W/mK	0.50 W/mK	0.72 W/mK	0.90 W/mK
Time (min)↓	Average Temperature (°C)			Average Temperature (°C)		
Initial	38.4	39.2	39.8	37.1	39.3	39.7
1	39.6	43.3	43.7	37.3	39.6	44.8
10	41.7	46.8	50.6	39.2	45.2	59.2
15	41.6	47.1	51.5	38.4	44.8	59.4
20	42.3	47.5	51.3	39.6	46.7	61.6
25	42.8	47.7	51.5	39.3	46.8	66.4
30	42.5	47.2	51.9	40.3	46.7	70.7
35	42.7	47.2	51.8	41.8	48.0	70.8
40	43.1	47.3	52.0	40.5	48.9	69.8
45	43.8	47.6	51.8	41.9	48.6	68.8
50	44.0	47.3	51.7	42.6	47.0	69.4
55	44.9	47.4	51.8	43.5	48.6	70.3
60	45.2	47.8	51.7	43.3	49.0	69.7

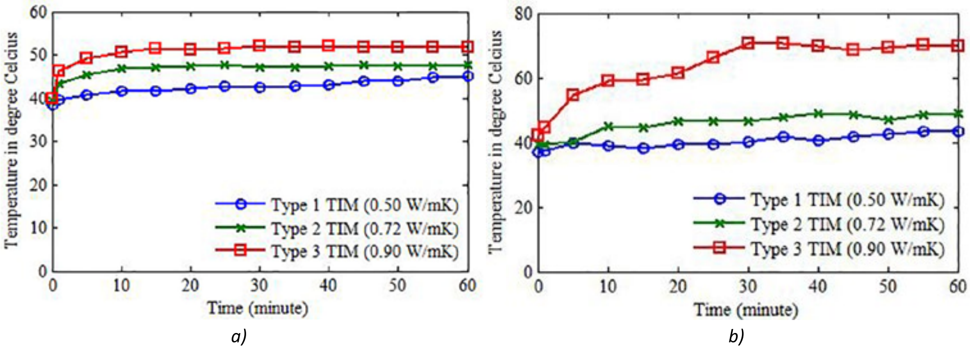
each of the LED luminaires were observed. These optical parameters were recorded after ten measurements rounds, and their average results are shown in the Table 3.

The rated luminous flux of 5 W COB-based LED luminaire is higher than that of 5 W SMD-based LED luminaire. In this study, it is clearly shown that the lumen output is directly affected by the value of thermal conductivity of the LED TIM. When the thermal conductivity of TIM increases, the lumen output of the LED increases. Due to the poor thermal conductivity of the thermal paste, heat accumulates in the interface between the LED substrate and heat sink, so the temperature of the LED chip increases and reaches a high level, which reduces the generation of photons as a result of a lower lumen output. Therefore, heat dissipation from the LED chip is one of the important factors to get the rated lumen output of these types of LED luminaires, which is improved by using higher thermal conductivity of the thermal interface materials.

The temperature of the end surface of the attached heat sink was measured and recoded for both types of LED luminaires when luminaires were at power on conditions. The sink area temperature were taken at the initial moment when the luminaires were switched on and the measurements were continued at intervals of five minutes for one hour. Table 4 shows the average temperatures in sink area as a function of time for both types of LED luminaires with three types of TIM used with different thermal conductivity. The experimental results are shown in Fig. 3, showing the established relationship between operating time (t_b) of LED luminaires

Table 5. Projected Initial Constant Values for Predicting the Temperature of the Sink with Consideration for Operating Time [Ref: Fig. 3]

LED type	COB-based 5 W LED luminaire			SMD-based 5 W LED luminaire		
TIM material	Type 1: thermal paste	Type 2: thermal paste	Type 3: thermal pad	Type 1: thermal paste	Type 2: thermal paste	Type 3: thermal pad
Initial constant value	Projected initial constant value			Projected initial constant value		
p	39.903	44.902	48.976	37.708	41.442	50.861
q	0.0021	0.0013	0.0013	0.0024	0.0034	0.007



a) *b)*

Fig. 3. Temperature at end surface area of the heat sink for a 5 W COB-based LED module (a) and an SMD-based LED module (b) as a function of operating time at room temperature (25 °C) using three types of TIM material

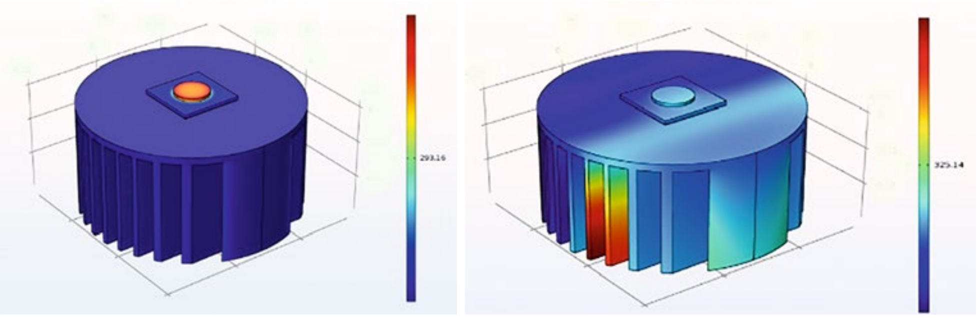
and the temperature of their sink area (T) for three different types of thermal interface materials. The application of the basic curve fitting method to obtain the dependence between the temperature of the sink area (T) or $f(t_b)$ and the operating time of the LED t_b is exponential and can be obtained empirically as an Eq. 1,

$$T = f\left(t_b\right) = p \cdot e^{q \cdot t_b}, \tag{1}$$

where p and q are the projected initial constant values for all two types of LEDs with different TIM materials (Table 5).

The temperature of the LED junction area due to the applied electrical power to the device usually increased during testing, and gradually heat was dissipated from the LED to the surface of the heat sink. This heat release usually depends on the thermal conductivity of the LED packaging materials used. Due to the low thermal conductivity of the TIM material, smooth heat dissipation to the environment is difficult. As can be seen from Fig. 3, the heat release temperature of the sink area is higher when using a higher thermal conductive TIM material for both COB and SMD-based LED luminaires. Therefore, generated junction temperature is more dissipated from LED chip area to its sink area, which gives to chip the ability to reduce excess heat generation. This keeps the health of the LED very good and maintains proper luminous flux as well as reliability.

Measuring the junction temperature of LEDs is very critical and not accurate under normal environmental conditions using an IR sensor or a thermocouple. The applied electrical power of the LED is only converted to light by (20–30)%, and the rest of the power is converted to heat, which caused damage to the LED devices. Therefore, it is very important that the excess heat of the LED junction area is dissipated from the LED into the environment. Currently, there are LED luminaires on the market that usually do not have proper thermal management due to the lack of information about the junction temperature of the LED chip. Therefore, designers of led devices need an easy method for predicting the junction temperature of LED luminaires, which will help them estimate the junction temperature and design LED luminaires with an ideal heat dissipation system. Here, the LED chip manufacturer provides the thermal characterization parameter (ψ_{JH}) to the LED luminaires manufacturer. Now it is possible for a LED luminaires designer to measure the temperature at the end position of the outer surface of LED heat sink. Thus, the junction temperature is calculated using the thermal characterization parameter (ψ_{JH}) from the LED junction



a) b)

Fig. 4. Temperature distributions of the COB-based LED by *COMSOL* software at the initial time (a) and after one-hour (b)

to the heat sink, which is defined by JEDEC in Eq. 2 as:

$$\psi_{JH} = (\mathrm{T}_J - \mathrm{T}_H) / \mathrm{P}_d, \tag{2}$$

$$T_J = P_d \cdot \psi_{JH} + T_H, \tag{3}$$

where, T_J, T_H are the junction temperature and heat sink area temperature respectively at steady state and P_d is the power applied. The thermal characterization parameter ψ_{JH} has the unit of °C/W.

4.2. Simulation Results for the Selected Type of LED Module

The simulation calculates temperature distribution and heat fluxes in the structure. Therefore, a COB-based LED chip was designed with mounting pads, thermal interface material such as thermal paste (type 1 and type 2) and thermal pad (type 3), and an aluminium heat sink placed under each LED as shown in Fig. 4. Transient finite element simulations were performed using *COMSOL* software to simulate temperature increase over time through the LED module to heat sink. It was assumed that the heat flow is created by the conduction between the heat source (LED chips) and the heat sink and convection from the package to the air. The heat flow through the bottom/outer surface of the LED heat sink, as well as the junction temperature of the LED chip have been taken from the thermal analysis of the LED luminaire model. In this model, the heat transfer occurs through conduction in the subdomains. The simulated results have been noted over a time period of 1 hour.

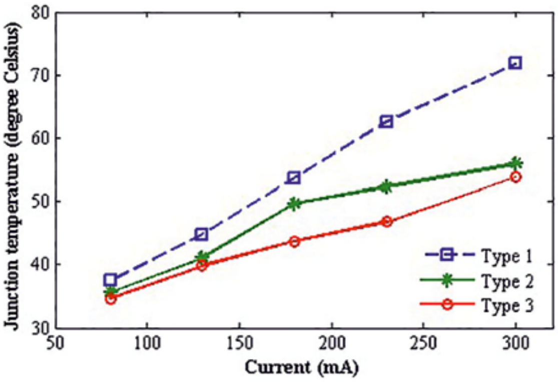


Fig. 5. The relationship between junction temperature and input current for 5 W COB-based LED module using three types of TIM material

4.3. Temperature Distribution of the COB-Based LED Luminaire with TIM as Thermal Pad

The temperature variations in the heat sink area (when using the TIM material as a thermal pad) over time, both for practical and software-simulation process are described in Table 6. The measured temperature in the sink area was taken when the device was in operation. The initial temperature of the LED was measured using an IR thermal imager. The initial value implies the minimum time taken to measure the value, but by this time, the temperature naturally begins to rise. For simulation, the initial temperature means that the device is exactly at the time when it is turned on. Therefore, the initial result of the simulation was an almost perfect position, that is at ambient temperature. Therefore, the measured initial temperature value was shown to be greater than the simulated results. The ambient temperature was set as 27 ˚C at the time of measurement. It is noticed that after 10 minutes when the almost steady state has observed, the percentage variation between the measured temperature and simulated temperature is in the range of about 6 %. A typical simulated diagram of heat distribution at the sink area has been illustrated in Fig. 4. The same thing appears as resemblance to actual nature.

Table 6. Measured and Simulated Temperature of the Sink Area over the Operation Time of COB-Based LED Module

Operation time (min)	Measured temperature (˚C)*	Simulated temperature (˚C)
Initial	39.8	33.1
1	43.7	43.9
10	50.6	47.4
15	51.5	47.3
20	51.3	49.0
25	51.5	49.5
30	51.9	49.7
35	51.8	50.5
40	52.0	50.9
45	51.8	51.8
50	51.7	52.1
55	51.8	52.5
60	51.7	53.1

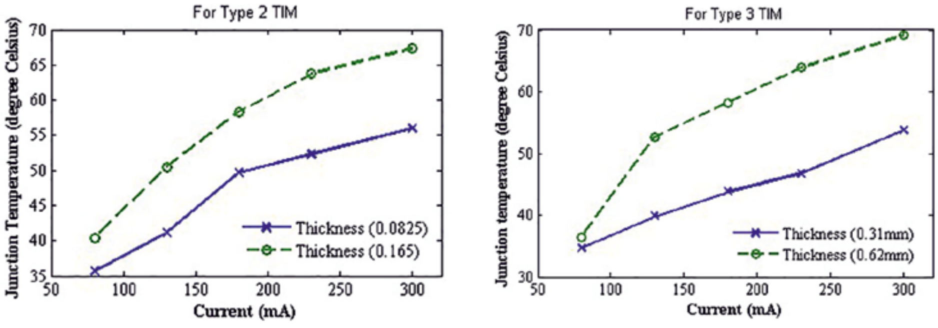
* The data given in this column and in Table 4 are puzzling. Indeed, as mentioned above, the radiator has a diameter of 7.7 cm and a height of 2.2 cm that is its volume V is approximately 97 cm^3. Even if we neglect the heat removal from the radiator, to heat it up to a temperature $T_1 = 47.3$ °C (which, according to Table 5, took place after 1 minute of LED module operation), energy $E_1 \leq C \cdot \rho \cdot V \cdot (T_1 - T_{amb})$. And since the radiator is made of aluminium, then $E_1 \leq 0.9$ J / (g · K) · 2.7 g / cm^3 · 97 cm^3 · (47.3–27) K ≈ 4785 J, and even if the entire consumed LED module power $P = 5$ W will be spent on heating the radiator, then on heating the radiator to the one given in Table 5 temperature of 47.3 °C, time t_1 will be required, not less than $E_1 / P \leq 4785/5 = 957$ s ≈ 16 min, not 1 min as follows from Table 5.

Remark from interpreter in Russian *E. Rozovsky*

4.4. Analysis of Simulation Results for a COB-Based LED Luminaire with Different Thickness of the TIMs and Drive Currents

The simulation was conducted in the two ways. First, the thickness of the TIMs was a fixed value while varied the drive current to get the value of junction temperature of the LED luminaires and, lastly, varied the thickness of the TIMs and drive current to monitor the junction temperature. The relationship between junction temperatures at different input drive current is shown in the Fig. 5. The curve shows that the junction temperature increases linearly (approximately) with increasing drive current of the LED. The junction temperature is highest for a type 1 TIM LED luminaire when the LED drive current is 300 mA and is nearly 72 ˚C. In the case of type 3 TIM LED luminaire, the junction temperature is 53.83 ˚C (drive current 300 mA), which is lower than other two TIMs.

Thus, it can be concluded that the heat dissipation from junction of the LED with the sink or the environment depends on the thermal conductivity of



a) b)

Fig. 6. The relationship between the junction temperature and the input current when varying the thickness of TIMs type 2 (a) and type 3 (b)

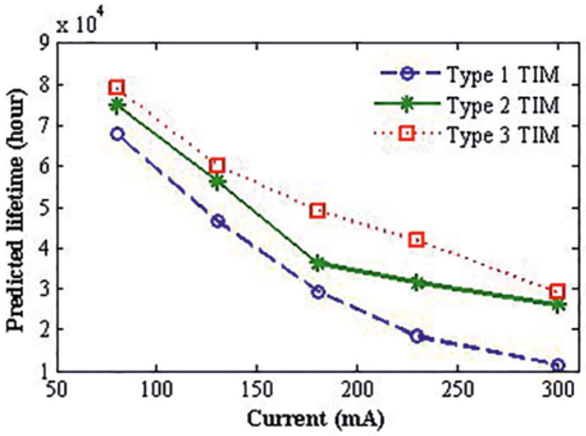


Fig. 7. Predicted lifetime depending on varying current for different TIMs

TIMs and other materials. Here the thermal conductivity of type 3 TIM is higher than other two.

The junction temperature of the LED luminaire changes when the thickness of the TIMs layer changes. In this experiment, the thickness of the type 2 and type 3 TIMs increases. When the thickness of the TIMs increases, the junction temperature of the LED also increases, as shown in Fig. 6. It can be seen that the junction temperature increases for a luminaire with an increased thickness of the TIM layer is higher, that is, up to the maximum at the drive current of 300 mA, the junction temperatures is 67.33 ˚C and 69.11 ˚C for type 2 and type 3 TIMs, respectively.

Therefore, it is assumed that increase in junction temperature of the LED luminaire depends not only on the increase in the drive currents, but also on the thickness of the TIM layers.

Predicting lifetime of a LED luminaire is the one of the important criteria for a LED manufacturer(s). In this experiment, a model based on inverse power law (exponential) is used to predict the lifetime for a LED luminaire [24]. From the model lifetime (L) of the LED:

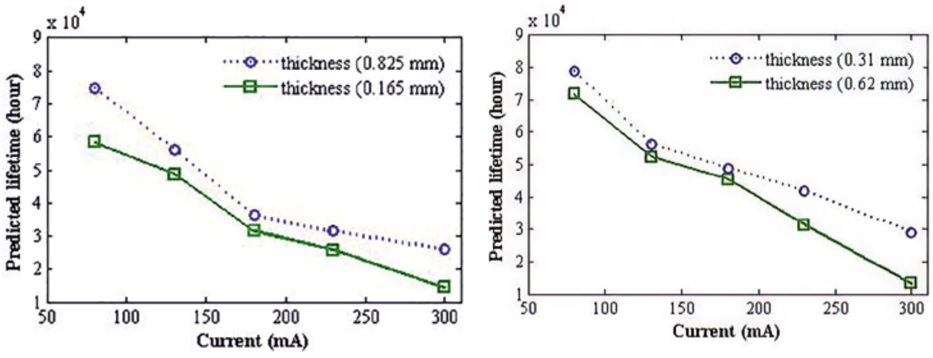
$$L = \mathrm{A}_{T_j} \cdot e^{-n \cdot T_j}. \qquad (4)$$

Here, according to the model [24], $A_{Tj} = 477337$, $n = 0.052$ and T_j is the junction temperature of the certain LED luminaire[1]. Using Eq. 4, you can calculate the predicted lifetime of the LED luminaire with the corresponding junction temperature with each type of TIM. The lifetime of the LED luminaire at different input drive currents is shown in Fig. 7. It can be seen that the lifetime of the LED luminaire is higher with a lower drive current. The type 3 TIM LED has the highest lifetime at various drive currents.

Similarly, the predicted lifetime of the LED luminaire with different thickness of type 2 and type 3 TIMs is calculated. Fig. 8 shows the predicted lifetime of the LED luminaire with different thickness of the TIMs at different input drive current. It can be seen that the lifetime of the LED luminaire decreases with increasing thickness of the TIM layer. As the thickness of the TIM layer increases, the heat release decreases, and as a result, the junction temperature increases. Therefore, the thickness of TIM layer is an important parameter for the designer or manufacturer.

5. CONCLUSION

The optical and thermal characteristics of these two types of LEDs with three types of TIM at dif-



a) b)

Fig. 8. Predicted lifetime depending on varying current when thickness TIM of the type 2 (a) and type 3 (b) changes

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[1] The article does not indicate the units of measurement for the parameters L and Tj, and at the same time the authors insist that the constants A_{Tj} and n are dimensionless.

– If we assume that A_{Tj} and n are measured, in hours and 1 / °C respectively and substitute in formula (6), the temperature of the *p-n* – junction, which is quite acceptable for LEDs, equal to 80 °C, then we obtain a service life of 7450 h, which is somewhat small.

Remark from interpreter in Russian E. Rozovsky ferent thermal conductivity due to the same input current and power were initially studied using laboratory measurements. This study compares the thermal/ heat dissipation of LEDs with three different TIMs, and the measured results demonstrate that the thermal pad provides very efficient heat dissipation performance and better lumen output compared to the other two. The relationship between LED's heatsink temperature and luminaire operation time of the LED luminaires was obtained. Similarly, the relationship between the junction temperature and the temperature of the LED heat sink was also predicted. Thus, due to proper heat management of LED components, their reliability can be enhanced. This study has shown that, despite technological progress, thermal management is still an important element of luminaire design. A thermomechanical model of commercially available COB-based LED luminaires with three types of TIMs at different input drive currents was studied using finite element method. The junction temperature of COB-based LED luminaire at different drive current with three different TIMs are compared and analysed. Type 3 TIM gives a lower junction temperature than the other two due to its higher thermal conductivity properties, which gives the more heat dissipation through it to the heat sink. It is concluded that the junction temperature increases with an increases in the input drive current and the thickness of TIMs, which reduces the lifetime of the LED. The results can be explained as verification study necessary for the design and simulation of thermal effects and thermal management of COB-based LED luminaires. At the same time, LED manufacturers should take into account that the increase in the junction temperature of the LED luminaire depends not only on the increase in drive currents, but also on the thickness of the TIM layers.

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