OPTIMAL DESIGN OF HEAT DISSIPATION MODULES FOR HIGH-POWER LED BASED ON THE TAGUCHI METHOD

by

Chien-Chung LIU, Maw-Tyan SHEEN*, and Shin-Fuh WANG

School of Mechanical and Automotive Engineering, Fujian University of Technology, University Town, Minhou County, Fuzhou City, Fujian Province, China

Original scientific paper
https://doi.org/10.2298/TSCI220329124L

The semiconductor component of InGaN-based blue light-emitting diodes (LED) emits white light when combined with a yellow phosphor mixture. However, owing to the lattice dislocations and defect points in GaN, it exhibits a high thermal resistance, which leads to heat accumulation and an increase in temperature. This is problematic as overheating causes LED to produce dark spots and lines and reduces the luminous flux and optical power of high-power LED. In this study, we propose a variety of optimal structures for heat-transfer modules and apply the proposed architectures in the assembly of high-power LED. First, the high-power LED substrate was coated with a film of aluminum nitride. Then, copper fins were connected to the vacant spaces in the circuit boards to increase the surface area of the heat-transfer region. The Taguchi method was used to identify the optimal substrate thickness, fin arrangement, and fin depth for the effective heat dissipation in a 12 W high-power LED. A dielectric layer was grown on the surface of the aluminum nitride film to serve as a passivation layer to insulate the patient. The passivation layer reduces the physical damage caused by thermal stress, thereby improving the service life and characteristics of heat-transfer modules. The proposed design not only yields a stable LED substrate (with low thermal stress) but also induces reliable heat transfer.

Key words: *high-power LED, aluminum nitride coating, fin, heat-transfer, Taguchi method*

Introduction

Currently, the widespread application of high-power LED is in great demand on the international mark. Furthermore, the qualitative and technical issues in these UV LED, such as low brightness, diverging light field, poor chromaticity, short life span, and low reliability, can be primarily attributed to material properties and insufficient heat dissipation. Self-heating of LED is an important issue that affects the reliability. Thermal droop has a significant impact on GaInN-based blue LED. Poor heat dissipation causes thermal effects that increase the chip's junction temperature. Consequently, this reduces the emitted photon energy and light efficiency. The increase in temperature will also cause the emitted spectrum to be red-shifted and decrease the quality of the color temperature. Overheating will cause a signifi-

* Corresponding author, e-mail: 13459400562@qq.com

cant change in the luminous characteristics of the LED, reduce the relative light output rate, and shorten the lifetime of the LED.

Khattak *et al.* [1] investigated the optimal thermal performance characteristics for given geometry of plate type fin heat sink using advanced finite element method (FEM) tool. The result showed that the fin heat sink was getting in comparison with the experiment. The discussed geometry is made available for better heat dissipation outcome. Chu *et al.* [2] perform an evaluation of the thermal performance on circuit board using experiment, while the air-flow management strategy for confined compartment is implemented. The result shows that the corresponding heat transfer performance is improved. Lopes *et al.* [3] investigated a kind of the improvement of radial plane fins heat sinks for natural convection cooling of LED lamps. Using the FEM, the study aims at further improvements by considering incomplete rectangular radial plane fins. The measurement results show that the best profile for the turning operation to obtain the radial plane fins lighter configuration. Motorcu *et al.* [4] investigated experimentally the effects of compressor speed, wastewater temperature and mass-flow rate in the waste heat recovery on the COP of mechanical heat pump. The Taguchi method was used to determine the efficiency of the chosen parameters on the system and optimum working conditions. Maji *et al.* [5] used the heat transfer enhancement of heat sink using perforated pin fins with linear and staggered arrangement. Comparing with the fins of various shapes with different perforation geometries. The study demonstrate that the perforation geometry heat transfer rate improves significantly. Park *et al.* [6] used a cooling system consisting of a hollow cylinder and a radial heat sink on the LED downlight. The study investigated the performance of heat sinks with various fin-types. The results show that the thermal performance of a radial heat sink is enhanced.

Some researchers in [7-10] used the ANSYS software to investigate the heat transfer characteristics of the high-brightness LED used in automotive headlights. The parameters discussed included the arrangement of LED, surface area and thickness of the heat sink, and changes in the slug, substrate, and heat sink materials. The results demonstrated no significant temperature difference between the uniformly distributed and annular arrangements of the LED. Moreover, the convection coefficient remained less than 50 W/m^{2}K with respect to the thickness and surface area of the heat sink. A significant temperature difference was noticed between the slug and the substrate with high thermal conductivity of the materials. Thus, this design could effectively reduce the surface temperature of the LED. Bera *et al.* [11] discussed the relationship between the luminous efficiency and surface temperature in LED based on experiments conducted over a wide temperature range and concluded that the driving current of an LED is linearly dependent on its driving voltage. Furthermore, the thermal resistance and impedance were observed to increase with an increase in power, inducing heat accumulation on the surface. This indicates that efficient heat dissipation is essential for the reliable operation of LED. The LED backlight modules ensure the high quality and reliability of LED. Some researchers in [12-14] conducted the thermal analysis of a flip-chip-packaged 280 nm nitride-based deep ultraviolet LED device (size: 100 mm × 100 mm) with an aluminum nitride (AlN) ceramic board as the substrate and heat transfer fins installed underneath. The overall thermal resistance was estimated to be 33 °C/W. Moreover, simulation-based analysis revealed that the rate of heat dissipation depended on the surface area of the LED, which was inversely proportional to the heat flux of the opposite surface. In general, the transfer of heat from main components is difficult in LED devices. Arik *et al.* [15] fabricated silicon carbide (SiC) and sapphire chips using different packaging methods to investigate the heat dissipation issue. The authors implemented ANSYS FEM to simulate the heat dissipation in 1 W LED chips fabricated using two packaging methods. The temperature distribution achieved by the SiC packaging method was relatively more uniform. Moreover, the surface temperature was lower than that obtained using the sapphire chip method, and this low surface temperature can be attributed to the higher thermal conductivity of SiC.

Arik *et al.* [16] used an infrared thermal imaging camera to capture the surface temperatures of SiC and sapphire chips fabricated using two different packaging methods. Petroski *et al.* [17] used ANSYS FEM to investigate the heat dissipation in a metal core printed circuit board and achieved an improved controllability of device variables. Petroski *et al.* [17] selected five control variables-LED pitch, dielectric layer thickness, circuit layer thickness, solder thickness, and ambient temperature. Room temperature and LED spacing were identified to be the most influential control factors. However, the determination of the optimal LED pitch is essential for an optical design with appropriate light mixing and uniformity. Therefore, in addition to optimizing the LED package and structure of the LED module to reduce their surface temperature and increase service life and reliability, the resistance of LED to high surface temperatures should also be enhanced.

All the mentioned studies only focused on the optimization of a single quality characteristic. However, ignored the interaction effects between process parameters, whereas the concept of interaction is essential in the manufacturing processes due to overlapping effect between process parameters that commonly occurs in practical applications. In this study, we analyzed the heat dissipation in a LED module by simulating its actual power using the FEM. Further, the structure of the heat transfer module was optimized based on a combination of experimental and simulated data. Our results indicate that the proposed module can effectively reduce the temperature of a 12 W high-power white LED from 102-65 °C on the LED surface. In addition, an experimental design obtained using the statistical Taguchi method involving the various fin parameters of the properties of different materials used for LED was shown to have effective design characteristics. The Taguchi method was used to identify the optimal parameters for heat dissipation, and the proposed module was verified to be capable of effectively dissipating the heat in LED.

The operating conditions and heat transfer mechanisms of high-power LED affect their luminous efficiency and service life. In this study, the Taguchi method was used to investigate the operating variables affecting the heat transfer and luminous efficiency of a high-power LED module. Statistical analysis was used alongside simulations to design more effective heat transfer modules for LED, enabling faster heat transfer to the ambient environment. The primary objective of the study was to reduce the surface temperature of the LED for long-term use and improve their luminous efficiency, and the strategy is expected to be used as a reference for future studies on high-power LED.

Methods

High-power LED require high heat dissipation capacities, fast heat transfers, and high thermal conductivities. In this study, we evaluated optimal designs for heat transfer modules for application in the assembly of high-power LED. First, the high-power LED substrate was coated with an AlN film to obtain an insulating layer with a high thermal conductivity. A copper fin was added to the vacant space in the LED circuit board to increase the surface area of the heat-transfer region. The Taguchi method was used to identify the optimal substrate thickness, fin arrangement, and fin depth for maximum heat transfer. The FEM was used to simulate heat transfer via the AlN coating on the LED substrate. Experiments and simulations were performed to optimize the design of the heat-transfer module. A combination involving external heat transfer fins was identified to be the most effective solution for the heat transfer problem in high-power LED. All the steps of the experimental procedure and simulation used in this study are summarized below.

Experimental steps to design a variety of heat-transfer structures.

Coating the high-power LED substrate with an AlN film

To coat the LED substrate with an AlN film, an ion-spraying process was used as the dry process. First, the AlN was ionized and sprayed on the LED aluminum substrate at a high temperature (1800 °C). The thicknesses of AlN films were controlled throughout the process. In this work, we report high in-plane thermal conductivities of 0.2 mm, 0.3 mm, and 0.5 mm thick AlN films measured via steady-state thermoreflectance in fig. 1(a). Depending on the films' crystalline structure, the AlN films, the bulk thermal conductivity of the AlN films at room temperature varied between 100 W/mK and 140 W/mK. The results show that more uniform coating of grain size, the higher the stable heat transfer. Research indicates that the 30 seconds time and 60 mm per second speed of coating were tested to the best of the solution with 0.5 mm thick. The AlN is a good conductor of heat in structural ceramic materials, with the thermal conductivity, K_{AlN}, of 140 W/mK. Thus, the AlN film improves thermal conductivity and electrical insulation. The heat flow coming from the junction, the thermal resistances of passivation layer, AlN and Al substrate are connected in series. The heat dissipation on the LED substrate is limited by the very low thermal conductivity of the dielectric layer, and the surface of the dielectric layer was used as a passivation layer on the AlN film surface, which acted as the thermal insulation layer. Analysis revealed that the proposed design reduced the physical damage caused by thermal stress and improved the service life and characteristics of the components. The LED was observed to exhibit stable heat transfer in reliability tests. Following the determination of the optimal thickness and surface area, the heat transfer structure for the high-power LED substrate was identified, as depicted in fig. 1(b).

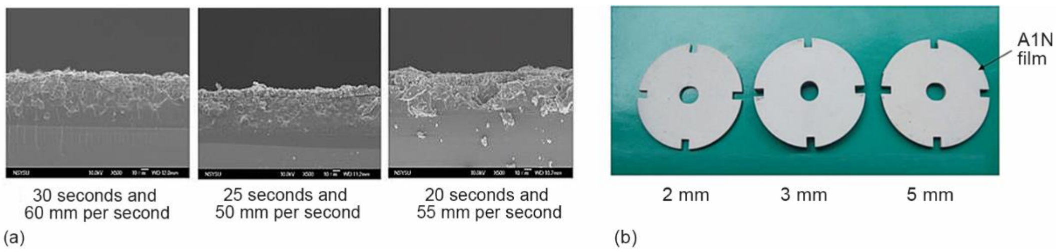

Figure 1. (a) Electron microscope images and (b) high-power LED substrate coated with the AlN film

Externally connecting the vacant space in the LED substrate to copper fins to increase the frontal surface area of the heat transfer region

The vacant space in the LED circuit board was externally connected to copper fins to enhance the frontal surface area of the heat transfer region. Copper fins were fabricated by bending copper sheets. The fin design incorporated grooves of different depths and widths. The optimization of the number of copper fins, which was considered to be a parameter in the Taguchi method, enabled the identification of the most effective heat transfer module for high-power LED, as depicted in fig. 2.

Figure 2. Vacant space in the LED substrate, externally connected to the copper fins at the front; (a) the LED circuit board, (b) integrating sphere, (c) and (d) groove type

Measurement of the luminous flux and temperature of high-power LED

An integrating sphere can be used to measure the luminous flux, spectral power, color co-ordinates, color temperature, color rendering, peak wavelength, input power, light efficiency, waveform diagram, as illustrated in fig. 3, and other parameters of a high-power LED. The different wattage of the LED is LED combined in the clockwise direction. In this study, the integrating sphere was used to measure the luminous flux generated by the high-power LED under different wattage parameters.

An infrared thermal imager was used to capture the temperature. We also use it to determine a heat source's 3-D location via multiple 2-D infrared thermography (IRT) images acquired using a thermal imager to show the thermal 3-D graphs of high-power LED, and the corresponding results are shown in fig. 4. The ORIGIN software was used to investigate the thermal 3-D graphs in this study, where *X*-axial and *Y*-axial are the distance of substrate located, and *Z*-axial is the surface temperature of the substrate. Figure 5 compares the thermal images of the high-power LED and the thermal 3-D graphs of general LED. The general LED type was not designed for the fin factors and AlN-coated substrate. The general LED type can raise the temperature of parts to above 80 °C. Evidently, the temperatures of the high-power LED are higher than those of their general-type counterparts.

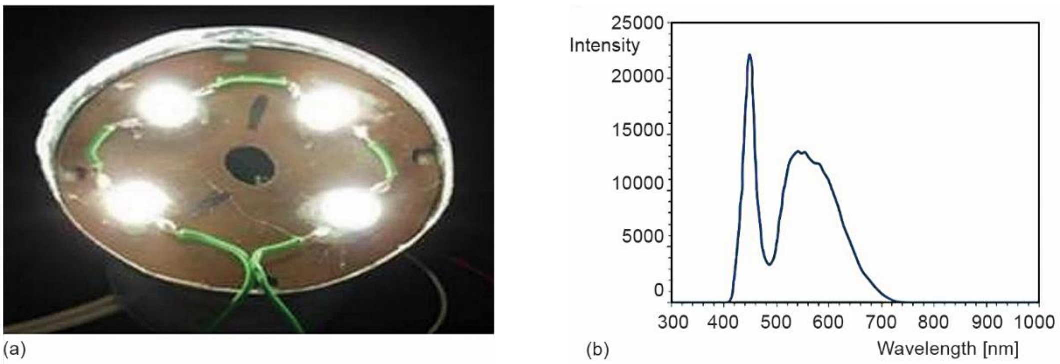

Figure 3. (a) The LED circuit board (5 W + 1 W + 5 W + 1 W) and (b) waveform of a high-power LED

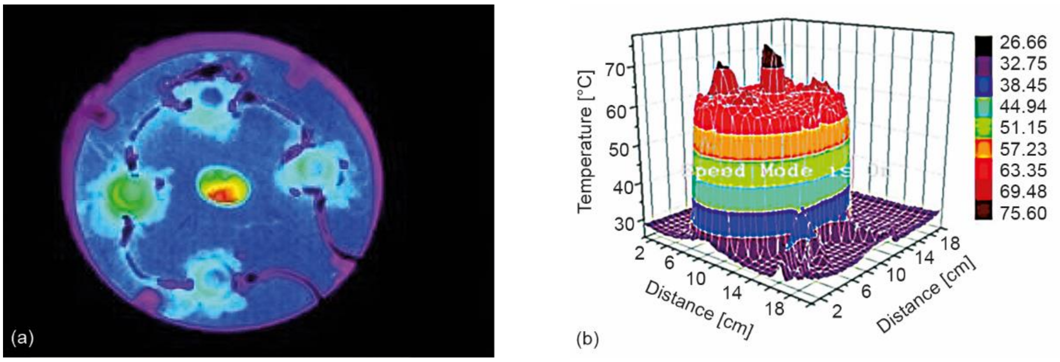

Figure 4. (a) Thermal image and (b) thermal 3-D graph of a high-power LED (5 W + 1 W + 5 W + 1 W)

Analysis of the heat transfer in high-power LED using FEM-based simulation

The FEM programs, MSC MARC and MENTAT, were used to investigate the heat transfer in this study. The proposed design optimization was applied to the theoretical analysis of the high-power LED module construction. The heat transfer was simulated using a 3-D FEM model incorporating heat conduction and air convection without radiant heat transfer. The temperature distribution on the AlN film in the high-power LED was determined:

$$\nabla(K\nabla T) = \rho c \frac{\partial T}{\partial t} \tag{1}$$

The heat convection on the boundary can be expressed:

$$-(K\nabla T)n = h\,(T - T_S) \tag{2}$$

where K, c, ρ, and h denote the thermal conductivity, specific heat, density, and thermal convection coefficient of the material, respectively, T_s – the room temperature, and n – the nor-

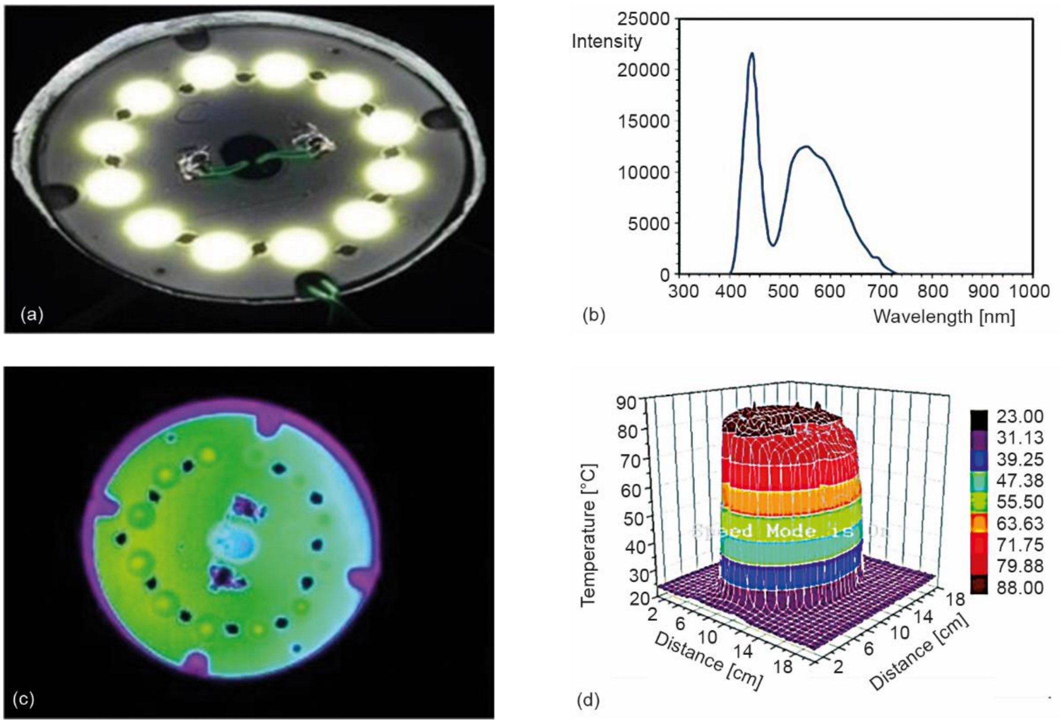

Figure 5. (a) (AL) LED, in general type, (b) waveform, (c) thermal image and (d) thermal 3-D graph of a general LED

mal unit vector. The properties of the material are summarized in tab. 1. The room temperature was 25 °C. Figure 6 depicts the mesh distributions of the geometry with groove on a cross-section of the solution domain, fig. 6(a), and the temperature distribution on the AlN film, fig. 6(b). The LED lighting was simulated by applying FEM to the substrate of the high-power LED. The AlN film served as a ceramic heat transfer module with the thermal conductivity of $K_{\mathrm{AlN}} = 140$ W/mK, indicating a good heat transfer effect. Then, the thickness and surface area of the film were optimized, and the most effective structure for heat transfer in a high-power LED was determined. Figure 7 depicts the temporal variations in the temperature of the AlN film on the high-power LED substrate, indicating that experimental data agree with the expected trend.

Table 1. Properties of different materials

	K [Wm^{-1}K^{-1}]	c [Jkg^{-1}K^{-1}]	ρ [kgm^{-3}]	h [Wm^{-2}K^{-1}]
Al	202	0.797	2700	–
AlN	140	0.920	1000	–
Copper	385	0.385	8900	–
Air	–	–	–	5

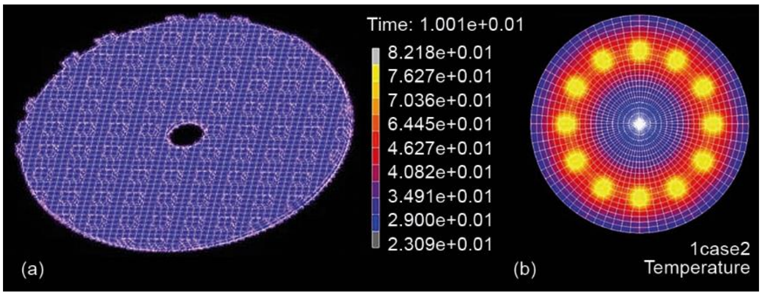

Figure 6. The FEM simulation on the AlN film substrate in a high-power LED (a) geometry with groove and (b) front face

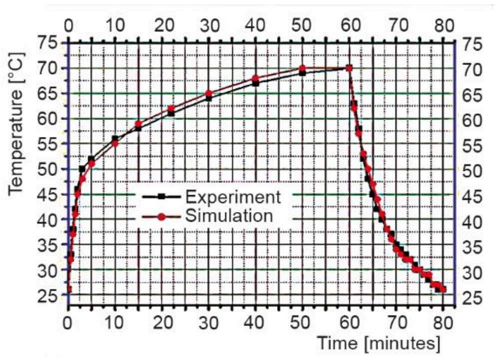

Figure 7. The FEM simulation of the AlN film substrate temperature (5 W + 1 W + 5 W + 1 W)

Experimental planning using the Taguchi method

In this study, the heat dissipation in a high-power LED through an AlN-coated substrate and installed fins was studied. Subsequently, Taguchi analysis was performed to optimize this design. The AlN-coated substrate was located near the posterior surface of the high-power LED, as shown in fig. 2. The following control factors were selected to analyze the heat dissipation characteristics of fins: (A) the types of grooves, (B) number of grooves, (C) width of each groove, (D) deep fin heat sink, (E) substrate drilling, (F) aluminum plate thickness, (G) high-power LED, and (H) copper fins. The (A) to (D) is the processing type of the heat sinks. The (E) is the arrangement of the holes. The (F) is aluminum plate's thickness. The (G) is high power LED configuration. The (H) is the extra copper to increase cooling capacity.

The signal-to-noise (S-N) ratio was used to measure the deviations in the quality characteristics from desired values, this was done using the Taguchi technique to convert the experimental results into values that can be used to evaluate the quality characteristics in optimum parameter analysis. Experimental observations were analyzed based on these control factors. The quality characteristic is LED life cycle of illuminating above certain lumen. Therefore, the S-N ratio is calculated for each factor level combination. The formula for the larger-is-better S-N$_{\mathrm{LTB}}$ ratio using base 10 log is:

$$MSD_{\mathrm{LTB}} = \frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2} \tag{3}$$

$$S\text{-}N_{\mathrm{LTB}} = -10 \times \log MSD_{\mathrm{LTB}} \tag{4}$$

where y is the given factor level combination and n – the number of responses in the factor level combination. Additionally, the S-N ratio of the average values, standard deviations, and integrated average values were calculated. Factor response and variation analyses were performed on the S-N ratios to determine the influence of each factor on the heat dissipation characteristics of each fin to measure the response value of each control variable. The optimization parameters are listed in tab. 2, and the factors considered in this experiment are listed in tab. 4. The effect of the variations in the factors considered in the experiment on the LED temperature are listed in tab. 3, and the orthogonal array, L-18 ($2^1 \times 3^7$), is provided in tab. 4.

The design array is used to systematically test various combinations over all combinations of noise factors. The average temperature value and standard deviation were calculated using the following equations, where T_1 and T_2 are the temperature measurements for the first and second tests, respectively.

average temperature value: $$Y = \frac{T_1 + T_2}{2} \tag{5}$$

standard deviation: $$S = \sqrt{\frac{(y_1 - \bar{y})^2 + (y_2 - \bar{y})^2 + (y_3 - \bar{y})^2 + ... + (y_n - \bar{y})^2}{n-1}} \tag{6}$$

S-N ratio: $$S\text{-}N_{\mathrm{STB}} = -10 \times \log\left(\frac{T_1^2 + T_2^2}{2}\right) \tag{7}$$

The effect of a control factor level is defined as the deviation of its related S-N ratio ε from the mean value. Hence, the average $\varepsilon_{\mathrm{A1}}$ and effect of E are given, respectively:

$$\varepsilon = (S\text{-}N)_n \quad \varepsilon_{A1} = \frac{1}{3}(\varepsilon_1 + \varepsilon_2 + \varepsilon_3) \tag{8}$$

$$\text{Effect}: E = [\max \varepsilon_A - \min \varepsilon_A] \tag{9}$$

Table 2. Fin parameters considered in this study

	Directions	Level 1	Level 2	Level 3
A	Groove type	Unidirectional	Double-sided	N.A.
B	Number of cooling channels	6	8	10
C	Groove width [mm]	1	2	3
D	Groove depth [mm]	1	2	4
E	Substrate drilling	N.A.	Two adjacent holes	Two holes diagonally
F	Aluminum plate thickness [mm]	2	3	5
G	High-power LED	5 + 1 + 5 + 1	3 + 3 + 3 + 3	5 + 3 + 3 + 1
H	Copper fins	N.A.	1	2

Table 3. Important factors that influence the temperature

		Directions				
Control factor		Level 1	Level 2	Level 3	Effect	Rank
A	Groove type	−58.19	−57.31	0.000	0.886	4
B	Number of cooling channels	−57.21	−57.88	−58.16	0.947	3
C	Groove width [mm]	−58.42	−57.93	−56.90	1.514	1
D	Groove depth [mm]	−58.03	−58.04	−57.17	0.863	5
E	Substrate drilling	−57.52	−58.14	−57.59	0.617	6
F	Aluminum plate thickness [mm]	−58.142	−57.542	−57.574	0.600	7
G	High-power LED	−58.09	−58.04	−57.12	0.965	2
H	Copper fins	−57.62	−57.97	−57.66	0.347	8

Table 4. Orthogonal table of the experiment, L-18 ($2^1 \times 3^7$)

	Control factor							
EXP	A	B	C	D	E	F	G	H
1	1	1	1	1	1	1	1	1
2	1	1	2	2	2	2	2	2
3	1	1	3	3	3	3	3	3
4	1	2	1	1	2	2	3	3
5	1	2	2	2	3	3	1	1
6	1	2	3	3	1	1	2	2
7	1	3	1	2	1	3	2	3
8	1	3	2	3	2	1	3	1
9	1	3	3	1	3	2	1	2
10	2	1	1	3	3	2	2	1
11	2	1	2	1	1	3	3	2
12	2	1	3	2	2	1	1	3
13	2	2	1	2	3	1	3	2
14	2	2	2	3	1	2	1	3
15	2	2	3	1	2	3	2	1
16	2	3	1	3	2	3	1	2
17	2	3	2	1	3	1	2	3
18	2	3	3	2	1	2	3	1

Results and discussion

In the Taguchi method, the target value of each factor was predefined before the experiment. The impact of each factor presented in tab. 1 on the performance of the proposed heat transfer modules of high-power LED was analyzed. The determined temperature factor shown in fig. 8 was compared with the lumen factor, as presented in fig. 9. The S-N ratio of the optimal characteristic was used to determine the best temperature conditions. The lumens orthogonal table used in the experiment is presented in tab. 5. Based on the experimental re-

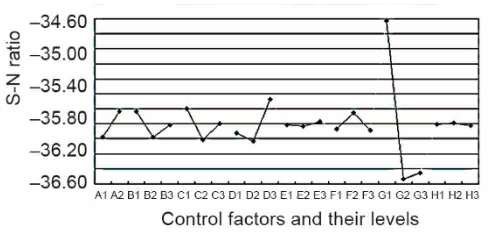

Figure 8. Response factor of the temperature diagram

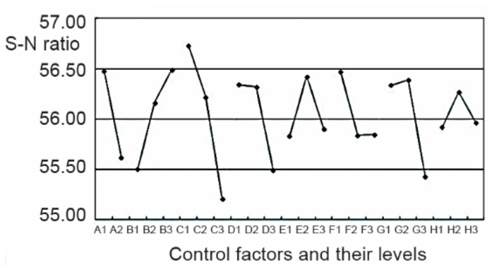

Figure 9. Luminous flux response factor of the lumen diagram

Table 5. Lumen orthogonal table

	Control factor												
EXP	A	B	C	D	E	F	G	H	T_1	T_2	Y	S	S-N
1	1	1	1	1	1	1	1	1	448.9	448	448.45	0.636396	51.28
2	1	1	2	2	2	2	2	2	546.4	545.5	545.95	0.636396	52.98
3	1	1	3	3	3	3	3	3	475.3	474	474.65	0.919239	51.77
4	1	2	1	1	2	2	3	3	566.8	565.6	566.2	0.848528	53.3
5	1	2	2	2	3	3	1	1	493.3	493.2	493.25	0.070711	52.1
6	1	2	3	3	1	1	2	2	505.5	503	504.25	1.767767	52.3
7	1	3	1	2	1	3	2	3	523.9	522.6	523.25	0.919239	52.62
8	1	3	2	3	2	1	3	1	466.4	465.2	465.8	0.848528	51.61
9	1	3	3	1	3	2	1	2	514.3	513.4	513.85	0.636396	52.46
10	2	1	1	3	3	2	2	1	508.2	506.6	507.4	1.131371	52.35
11	2	1	2	1	1	3	3	2	524.8	524	524.4	0.565685	52.63
12	2	1	3	2	2	1	1	3	490.6	489.3	489.95	0.919239	52.05
13	2	2	1	2	3	1	3	2	502	500.9	501.45	0.777817	52.25
14	2	2	2	3	1	2	1	3	494.8	493.8	494.3	0.707107	52.12
15	2	2	3	1	2	3	2	1	534.7	533.7	534.2	0.707107	52.8
16	2	3	1	3	2	3	1	2	505.2	504.4	504.8	0.565685	52.3
17	2	3	2	1	3	1	2	3	521.9	520.5	521.2	0.989949	52.58
18	2	3	3	2	1	2	3	1	537	535.8	536.4	0.848528	52.83

sults, the optimal structure of the heat transfer module for high-power LED was determined. The FEM simulation was conducted to accurately predict the temperatures at which high-power LED stopped working. The simulation results were used to evaluate the parameters and obtain the heat-transfer module with the lowest maximal operational temperature. Hence, the best settings to design are A1, B3, C1, D1, E2, F1, G2, and H2 based on the experimental results for maximizing lumen.

Conclusions

In this study, a number of optimized heat transfer structures were designed for assembling high-power LED. The high-power LED substrate was first coated with an AlN film, and copper fins were added to the vacant spaces on the LED circuit board to increase the surface area of the heat transfer module. The Taguchi method was used to identify the optimal substrate thickness, fin arrangement, and fin depth for a 12 W high-power LED. The FEM was used to simulate the temperature of the LED module for analyzing its heat transfer mechanism. Experiments and simulations were conducted to optimize the structure of the heat transfer module, and based on the corresponding results, the following conclusions can be drawn:

- The results demonstrate that the luminous flux of LED exhibits a sensitive dependence on temperature. The average measurement error was less than 8.39%, error = (experimental value − analog value / experimental value, which shows that the heat transfer in high-power LED can be effectively predicted based on experiments and FEM simulations.
- A number of heat transfer modules for high-power LED were analyzed. The groove width was obtained by optimizing the related parameters using the Taguchi method. Through the results, economic considerations, and larger-is-better S-N ratio of the Taguchi Method could be the optimizing structure to create an industrial manufacturing in search of saving time and a flexibility of product. Analysis revealed that the thickness of the aluminum plate in the LED has the highest impact on the LED temperature, and an aluminum plate thickness of 2 mm was determined to be optimal. Unidirectional grooves were observed to be the most effective, with the optimal number of heat transfer channels being 10, optimal width of fin channels being 1 mm, and optimal depth of fin channels being 1 mm. The substrate was diagonally drilled with two holes and equipped with one copper bump. These were determined to be the optimal parameter values to maximize the heat transfer in high-power LED.
- Experiments and simulations were performed to optimize the structure of the heat-transfer module. Using the optimal heat-transfer module, the temperature of a 12 W high-power white LED module was effectively reduced from 102 °C to 65 °C on the surface.

A heat-transfer module with a high heat transfer capacity and high thermal conductivity can effectively facilitate the heat transfer in high-power LED. This study is expected to serve as a helpful reference for the future studies on the heat dissipation in LED.

Nomenclature

c – specific heat capacity, [$\mathrm{Jkg^{-1}K^{-1}}$]
E – factor efficiency
h – heat transfer co-efficient, [$\mathrm{Wm^{-2}K^{-1}}$]
K – thermal conductivity, [$\mathrm{Wm^{-1}K^{-1}}$]
n – number of responses
S – standard deviation
S-N – signal-to-noise, [dB]
T – temperature, [°C]
T_1, T_2 – temperature measurements for the first and second tests
Y – average temperature value
y – observed data

Greek symbols

ε – mean value
ρ – density, [$\mathrm{kgm^{-3}}$]

T_s – room temperature, [°C]

References

[1] Khattak, Z., *et al.*, Thermal Analysis and Parametric Optimization of Plate Fin Heat Sinks Under Forced Air Convection, *Thermal Science, 26* (2022), 1B, pp. 629-639
[2] Chu, W. X., *et al.*, Thermal Performance Analysis and Heat Transfer Enhancement Study in an Antminer Mining Machine, *Journal of Thermal Science and Engineering Applications, 13* (2021), 2, 021011
[3] Lopes, Antonio, M. G., *et al.*, Costa Improved Radial Plane Fins Heat Sink for Light-Emitting Diode Lamps Cooling, *Journal of Thermal Science and Engineering Applications, 12* (2020), 4, 041012
[4] Motorcu, A. R., *et al.*, Effects of Control Factors on Operating Temperatures of a Mechanical Heat Pump in Waste Heat Recovery: Evaluation Using the Taguchi Method, *Thermal Science, 26* (2018), 1A, pp. 205-222
[5] Maji, A., *et al.*, Numerical Investigation on Heat Transfer Enhancement of Heat Sink Using Perforated pin Fins with Inline and Staggered Arrangement, *Applied Thermal Engineering*, *125* (2017), 1, pp. 596-616
[6] Park, S. J., *et al.*, Thermal Performance Improvement of a Radial Heat Sink with a Hollow Cylinder for LED Downlight Applications, *International Journal of Heat and Mass Transfer, 89* (2015), 1, pp. 1184-1189
[7] Li, J., *et al.*, Analysis of Thermal Field on Integrated LED Light Source Based on COMSOL Multi-Physics Finite Element Simulation, *Physics Procedia, 22* (2011), 1, pp. 150-156
[8] Yin, L., *et al.*, Thermal Design and Analysis of Multi-Chip LED Module with Ceramic Substrate, *Solid-State Electronics, 54* (2010), 1, pp. 1520-1524
[9] Kikuchi, K. *et al.*, Fluid and Thermal Analysis for LED Headlamp with Parametric Studies, *SAE Technical Paper, 1* (2007), 1, 1039
[10] Hu, J., *et al.*, Thermal and Mechanical Analysis of Delamination in GaN-Based Light-Emitting Diode Packages, *Journal of Crystal Growth, 288* (2006), 1, pp. 157-161
[11] Bera, S. C., *et al.*, Temperature Behavior and Compensation of Light-Emitting Diode, *IEEE Photonics Technology Letters, 17* (2005), 11, pp. 2286-2288
[12] Shatalove, M., *et al.*, Thermal Analysis of Filp-ChipPackaged 280 nm Nitride-Based Deep Ultraviolet Light-Emitting, Diodes, *Applied Physics Letters, 86* (2005), 1, 201109
[13] Narendran, N., *et al.*, Life of LED-Based White Light Sources, *IEEE/OSA Journal of Display Technology, 1* (2005), 1, pp. 167-171
[14] Kikuchi, K., *et al.*, An Approach to Predicting LED Junction Temperatures with Fluid and Thermal Analysis," *Journal of Passenger Car: Mechanical Systems Journal, 114* (2005), 6, pp. 888-895
[15] Arik, M., *et al.*, Thermal Management of LED: Package to System," *Proceedings of SPIE, 5187* (2004), 1, pp. 64-75
[16] Arik, M., *et al.*, Chip Scale Thermal Management of High Brightness LED Package, *Proceedings of SPIE, 5530* (2004), 1, pp. 214-223
[17] Petroski, J., Spacing of High-Brightness LED on Metal Substrate PCBs for Proper Thermal Performance, *IEEE Intersociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems, 2* (2004), 1, pp. 507-514

Paper submitted: March 29, 2022
Paper revised: June 30, 2022
Paper accepted: August 10, 2022