Letter

Evaluation of the Light Output Properties of White Massed-LEDs Light Sources and the Verification of Their Heat Radiation Effects by Thermal Fluid Analysis

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ABSTRACT

We investigated light output properties of white massed-LEDs light sources and their characteristics of temperature rise effects. In the white massed-LEDs light sources with heat radiation countermeasures, we found that the decrease of light output under the high forward current condition was alleviated. The thermal fluid simulation analysis of heat radiation effects of white massed-LEDs light sources indicated that the attaching heat sink to light source board material was effective in not only aluminum board but also glass-epoxy board. And it was confirmed that the LED element temperatures were held less than 60°C in the rated lighting condition for both of them.

KEYWORDS: white LED, InGaN, light output, heat radiation, thermal fluid analysis

1. Introduction

Recently, the high-luminance blue LED (light emitting diode) using InGaN series materials has been developed, and the white LED in which a YAG phosphor ($(Y,Gd)_3Al_5O_{12}: Ce$) is coupled with a blue LED has been introduced. Attention has been paid to LEDs as a fourth illumination source succeeding the incandescent lamp, the fluorescent lamp, and the HID lamp. This is because the LED, which is a solid-state, illuminating diode, has features such as small size, long life, and absence of mercury. Furthermore, it is expected to offer improved energy conversion efficacy and the realization of energy-savings^{1)~8)}. However, it is necessary to obtain high light output by means of massing arrays of LEDs in order to make a suitable illumination source, since the light output for one LED is small compared to the output of traditional light sources.

On the other hand, when an electric current flows through a conductor with electrical resistance, it inevitably generates heat, and performance deterioration of many electronic parts occurs as a result of an increase in temperature due to heat generation. Thus, the design of the heat radiation for electronic equipment is now regarded as mandatory as high-density electronics have been developed⁹⁾. Regarding the LED, the heat is radiated simultaneously with the light emission and the light output is decreased in parallel with an increase in the temperature due to heat from the elements. Therefore, when LEDs are massed as illuminating light source, heat radiation design for suppressing a reduction in the light output is an important subject^{10)~12)}. Hence, in this report, various kinds of white massed-LEDs light sources were prepared and their light output properties were evaluated

in order to understand the necessity of heat radiation promotion measures. Then, thermal fluid simulation analyses were made with various kinds of white massed-LEDs light sources in order to verify the heat radiation effects for the basic study of heat radiation design.

2. Experiment

In this experiment, sixteen surface-mount white LEDs (manufactured by Nichia Chemical Industries: NSCW100), available on the market, in which a blue LED of the InGaN series is coupled to a YAG phosphor, were amassed by being mounted on a 30×30mm board, 1.0mm thickness, in straight lines forming a 4×4 matrix with a pitch of 7.5mm to create a sample of white massed-LEDs light source. Two kinds of boards, glass-epoxy and aluminum, were used, and also versions with a multipurpose, aluminum heat sink with height of 15mm firmly attached to the back of the boards by silicone adhesive were prepared to make four kinds of white massed-LEDs light source samples in total.

Evaluation of the light output properties for each white massed-LEDs light source sample was made by measuring the luminous intensity distribution with the forward current varied in the range from 0mA to 100mA and also by calculating the total luminous flux using the zonal factor method. On the other hand, the surface temperature of each white massed-LEDs light source sample under each lighting condition was measured by a thermo-viewer to obtain the relationship between an increase in temperature and the light output properties. Also, the spectrum distribution in the range of wave length from 300nm to 800nm for each white massed-LEDs light source sample under each lighting condition was

Fig. 1 Simulation model figures of surface-mount white LEDs.

Table 1 Physical properties of each material for simulation model.

Modeling position	Reference material	Density (kg/m ³)	Specific heat (J/kg·K)	Thermal conductivity (W/m·K)
LED chip	Sapphire	3.966×10^3	8.485×10^2	4.013×10^1
Package	Alumina	3.886×10^3	8.353×10^2	3.259×10^1
Epoxy resin	Epoxy resin	1.850×10^3	1.100×10^3	3.000×10^{-1}
Gold wire	Gold	1.926×10^4	1.309×10^2	3.134×10^2
Electrode	Nickel	8.832×10^3	4.674×10^2	8.690×10^1
Solder	Tin	7.170×10^3	2.280×10^2	6.660×10^1
Copper foil pattern	Copper	8.866×10^3	3.916×10^2	3.958×10^2
Glass-epoxy board	Glass-epoxy	1.999×10^3	1.256×10^3	8.500×10^{-1}
Aluminum board, Heat sink	Aluminum alloy	2.700×10^3	8.690×10^2	1.800×10^2

Fig. 2 Simulation model figures of white massed-LEDs light source samples.

measured in order to evaluate changes in the light emission spectrum.

The thermal fluid simulation analysis was made using the multipurpose thermal fluid analysis software (made by CD Adapco Japan: STAR-CD). Fig. 1 shows the simulation model of a single surface-mount type white LED. A blue LED element of $350 \times 350 \times 100 \mu\text{m}$ is die-bonded at the center of the bottom surface inside the package made of alumina with $1.2 \times 3.0 \times 1.2 \text{ mm}$ outer dimensions, and the blue LED element is connected to gold plated nickel electrodes by wire-bonding with gold wires. Furthermore, YAG phosphor is painted on the upper portion, surrounding the blue LED element, and the inside of the package is filled with the epoxy resin and mold-formed. The anode and cathode electrodes of the surface mount type white LED thus packaged are soldered to the copper foil traces to mount it.

For the simulation analysis, a basic study was made first by comparing the surface temperature of actual equipment models and simulation models regarding white single-LED light source samples, which were made of pieces of surface-mount white LED installed at the center of boards $30 \times 30 \text{ mm}$ with thicknesses of 1.0 mm of glass-epoxy or aluminum. The range of modeling in the simulation analysis was a simulated space of $80 \times 80 \times 130 \text{ mm}$, and the wall temperature was set constant at 25°C . By the way, this simulation was a steady-state analysis, and the first-order upwind differencing schemes was applied. Also, it was assumed that, when a piece of LED is lighted at a forward current of 20 mA (forward voltage 3.6 V), 6 mW is obtained as the light output and the remaining 66 mW is converted to heat in order to set the quantity of heat generation for the LED element. The physical properties of each material input composing the simulation model are shown in Table 1¹³⁾. However, a consultation session was held with the manufacturer of the glass-epoxy board, since its physical properties were unknown, and the values were finally judged to be questionable. Thus, the value of heat conductivity that was revised through counter-checking of the surface temperature of the actual equipment model and the simulation model was applied for the glass-epoxy board. Also, the gas in the simulated space was assumed as air with molecular weight of 28.96 so that it was set as the ideal gas to satisfy the conditional equation of gas.

Simulation models of the white massed-LEDs light source samples in the form of a 4×4 matrix, which are models based upon the white single-LED light source samples, are shown in Fig. 2. The thermal fluid simulation analysis was made on each white massed-LEDs light source sample to obtain the surface temperature and element temperature of each and to examine their heat radiation effects.

3. Results and Consideration

Fig. 3 shows the light output (total luminous flux) of each white massed-LEDs light source sample versus the

forward current, and Fig. 4 shows the maximum surface temperature (actually measured value). From Fig. 3, it was verified that, although there is no large differences in the light output between the samples at a forward current condition of around the rated 20 mA , the light output does not increase linearly when the forward current is increased, the light output starts to decrease at the boundary of the maximum values, and outstanding differences in the properties appear between the samples. From Fig. 4, it was noted that there are differences in the increases in temperature among the samples, and it was verified that the increase in temperature is smallest in the sample with the aluminum board, which has an excellent thermal conductivity, with the heat sink installed, and that the increase in temperature is largest in the sample with glass-epoxy board alone, for which the thermal conductivity is poor. Also, it was verified that the increase in temperature is smaller in the sample with glass-epoxy board with the heat sink than it is in the sample with the aluminum board alone, and it was revealed that such differences in temperature increases significantly affect the light output properties and that the light output is improved in parallel with an increase in the heat radiation effect. By the way, the luminous efficacy of each white massed-LEDs light source sample versus the forward current is shown in Fig. 5, and it was verified that, although the luminous efficacy is reduced in parallel with an increase in the forward current with every sample⁹⁾, the reduction is suppressed more in the samples with the higher heat-radiation effect.

Fig. 3 Light output of each white massed-LEDs light source sample.

Fig. 4 Maximum surface temperature for each white massed-LEDs light source sample.

Fig. 5 Luminous efficacy for each white massed-LEDs light source sample.

Fig. 6 The change of the emission spectrum in the glass-epoxy board sample.

The spectrum distributions of the glass-epoxy board in the conditions of lighting with the forward current at 20mA and at 80mA are shown in Fig. 6. By this figure, it was verified that the peak emission wavelength of the blue LED shifted toward the longer wavelengths from 465nm to 471nm in parallel with an increase in the forward current. This was caused by the band gap of the InGaN active layer in the blue LED getting smaller due to an increase in temperature. Owing to the shift of the peak emission wavelength of the blue LED away from the excitation wavelength zone of the YAG phosphor, the emission of yellow light from the YAG phosphor was reduced. As a result, the emission color is changed from chromaticity coordinates 0.28x and 0.23y to 0.22x and 0.23y, a blue-tainted white. Since components of the wavelength zone with high relative luminous efficiency are reduced due to this change in emission spectrum, this also counts as one of factors reducing the luminous flux¹⁰⁾. From the above results, it can be said that measures to promote heat radiation with white massed-LEDs light sources are extremely important, not only for improving

Fig. 7 Maximum surface temperature for each white single-LED light source sample.

Table 2 Surface and element maximum temperature of each white massed-LEDs light source sample obtained by simulation analysis at a forward current of 20mA.

Sample	Maximum temperature (°C)	
	Surface	Element
Glass-epoxy board	90.7	95.5
Aluminum board	74.3	78.6
Glass-epoxy board with heat sink	55.1	59.1
Aluminum board with heat sink	50.4	54.1

the light output properties, but also for securing various properties required for illumination sources.

Fig. 7 shows the measured results of the actual equipment model and the results of the simulation model

regarding the maximum surface temperature versus the forward current for each white single-LED light source sample. In this figure, it is verified that the measured results of the actual equipment model and the results of the simulation model nearly match for the glass-epoxy board sample. On the other hand, the results of the simulation model were somehow higher than the measured results of the actual equipment model for the aluminum board sample, but the results of the simulation model were judged appropriate because the tendencies of increase were nearly equal. Hence, the thermal fluid simulation analysis was made on the white massed-LEDs light source samples in view of these results.

Table 2 shows the maximum surface temperature and the maximum element temperature for each white massed-LEDs light source operating at a rated forward current of 20mA that were obtained by the simulation analysis, and Fig. 8 shows the surface temperature distribution obtained in a similar manner. When the results of the simulation model for the maximum surface

Fig. 8 Temperature distribution figures for each white massed-LEDs light source sample obtained by simulation analysis at a forward current of 20mA.

temperature of each white massed-LEDs light source sample is compared with the measured results on the actual equipment model (forward current 20mA), the former shows a 20°C higher level at the maximum. This is considered attributable to the simulation space in the modeling range, which was set as small, $80 \times 80 \times 130$ mm, for calculation in the simulation analysis, which caused the inside of the simulated space to be filled with heat generated by the massed LEDs and triggered an excessive increase in temperature. By the way, although expanding the simulated space in the modeling range was once considered in view of these results, setting a limited simulated space is considered more meaningful for examining the heat radiation effect from the view point of it being closer to a practical application, because it is considered necessary to fit white massed-LEDs light

sources in a device with limited volume in order to use them as actual illumination sources.

As shown in Table 2 and Fig. 8, it was verified by the simulation analysis that a high heat radiation effect is obtained in the white massed-LEDs light source samples with heat sinks in either the glass-epoxy board or aluminum board, and it was shown that the maximum element temperature can be suppressed below 60°C. Accordingly, it was assured that, even with the glass-epoxy board, which does not have thermal conductivity as good as that of the aluminum board, the generated heat can be emitted efficiently toward the outside by installing a heat sink. Therefore, it is considered that the shape and form of the heat sink and the method of its installation are more effective measures for promoting heat emission of the white massed-LEDs light sources than is the selection

of the board materials. Accordingly, in the future we plan to study the heat emission design for white massed-LEDs light sources fitted in and unified with apparatus based upon this knowledge.

4. Conclusion

The light output properties of white massed-LEDs light sources were evaluated and it was verified that measures to promote heat emission improves the light output properties. Furthermore, these measures are important for securing desirable luminous efficacy and emission spectrum properties. Also, as a result of the evaluation of the heat radiation effect by thermal fluid simulation analysis, it was assured that the installation of a heat sink on white massed-LEDs light sources was very effective with any of the board materials and that it enables the suppression of the LED element temperature below 60°C.

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