3-Dimensional Module for LED Lighting Having Wide Light Distribution

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One of the advantages of flexible printed circuit (FPC) is that it can keep various shapes due to its highly flexible nature. By using this advantage, the light distribution property can be changed in a light-emitting diode (LED) lighting using LEDs with high directivity. However, the low thermal conductivity of FPC had considerably limited its application to LED lighting. In order to solve this challenge, we developed a high heat diffusion structure that greatly improves FPC's thermal conductivity and a gluing technique that enables 3-dimensional constitution of FPC. Thereby we made it possible to realize an LED module in which the FPC controls light distribution property with high heat diffusion. This newly developed technique is also applicable to high output LED.

Keywords: FPC, heat diffusion structure, 3-dimensional module

1. Introduction

In the illumination accounting for 10-20% of the energy consumption, recently, conventional electric bulbs, such as incandescent lamps or fluorescent lamps have been exchanged for LED*1 lighting thanks to a surge of energy saving consciousness. As the LED has high directivity, the light distribution angle*2 of the LED on a circuit board is confined to 120 degrees. Therefore, it has been necessary to widen the light distribution with a light reflector and a prism lens[(1),(2)]. In addition, since the luminous efficiency of LEDs decreases with the LED's temperature rise due to use at a high electric current, it has been necessary to spread heat emitted from such LEDs and cool them. In such a case, we have used a metal printed circuit board (metal-PCB) on which a wiring is formed through an insulating layer on the aluminum board.

On the other hand, as the FPC made by copper foil and polyimide (PI) resin film has a lot of advantages (light weight, thin, bendable and any others), it is widely used in mobile devices[(3)]. FPCs have superior characteristics of high insulation performance and high heat resistance, but heat diffusion performance is low because of the lowness of thermal conductivity of PI.

In order to solve this challenge, we improved the heat diffusion performance to equal a metal-PCB by a new heat diffusion structure, and we developed a technique for gluing the FPC to a 3-dimensional substrate. Thereby, we made it possible to get a wider light distribution angle without a light reflector and a prism lens. In this report, we discuss these in detail.

2. New Heat Diffusion Structure

2-1 Development of a new heat diffusion structure

When a high cooling performance has been required in an LED light use, we have glued the FPC to a flat heat sink and used it. However, as the thermal conductivity of PI resin and glue (epoxy resin) is less (below 0.2 [W/mK]) than one of the insulating layers of the metal-PCB (**Table 1**), the FPC has more thermal resistance to conducting heat to a heat sink than the metal-PCB. In order to solve this challenge, we developed a new heat diffusion structure of placing insulating resin, whose thermal conductivity is equal to one of the insulating layers of the metal-PCB, between a heat sink and a copper circuit layer and under the LEDs.

Table 1. Thermal conductivity of materials

Material	Thermal conductivity [W/mK]
Polyimide (PI)	0.2
Epoxy resin	0.2
Insulated layer of metal PCB	1.0-3.0
Aluminum	230

We calculated the cooling performance of the new heat diffusion structure by a finite element method. **Figure 1** shows the calculation results. With a rise of the thermal conductivity of the filled resin, the LED temperature rise of a new FPC with the heat diffusion structure is decreased. Thus, the LED temperature rise is reduced to the same level as the metal-PCB. The calculation results proved the effectiveness of the new heat diffusion structure.

Next, we made test LED modules with the new heat diffusion structure for measuring the cooling performance (**Photo 1**).

A procedure for measuring an LED temperature is described below. We repeated measuring the voltage of LEDs at fine electric current after operating at a current of 0.3 amperes for 15 seconds. After the operation had

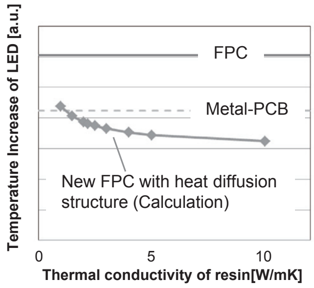


Fig. 1. Calculation result of the new heat diffusion structure

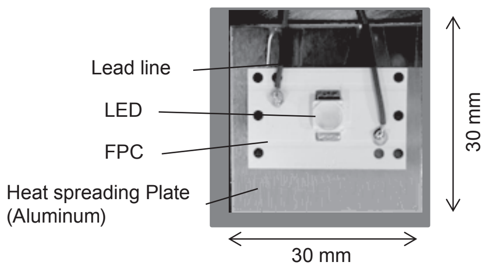


Photo 1. Test LED module for evaluating the cooling performance

been repeated 60 times, the voltage at fine electric current was stabilized. We derived temperature increase in the LED by calculating the voltage in consideration of temperature–voltage characteristics*[3].

Figure 2 shows the results of measuring the LED temperature rise. The new heat diffusion structure cools LEDs more than the conventional model. This experimental result corresponds with one of the calculation.

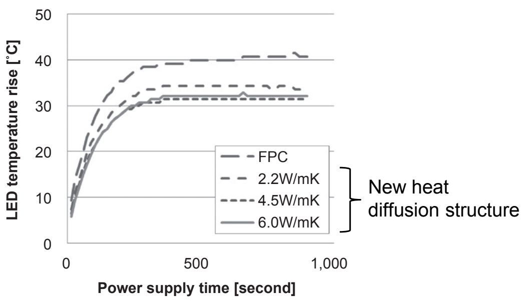


Fig. 2. Experimental result of the cooling performance

2-2 Reliability of the new heat diffusion structure

The thermally conductive gluing resin used for the LED module contains fillers in the epoxy based resin. We evaluated the reliability of the peel strength of this thermal resin.

Figure 3 shows the test piece and measuring method. Environmental tests were performed for the peel strength in high temperature storage (125˚C), low temperature storage (-40˚C), high temperature and high humidity storage (85˚C/ 85%RH) and temperature cycling (-40˚C-+125˚C). The results of environmental tests show that the peel strength was approximately 1,000 g/cm just after making test pieces, and remained unchanged after being exposed to each test in **Fig. 4**.

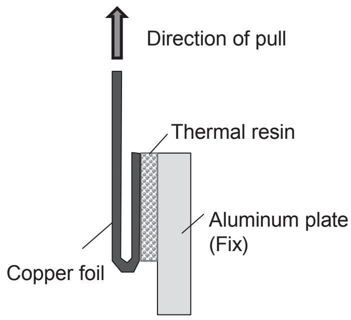


Fig. 3. Test piece and measuring method

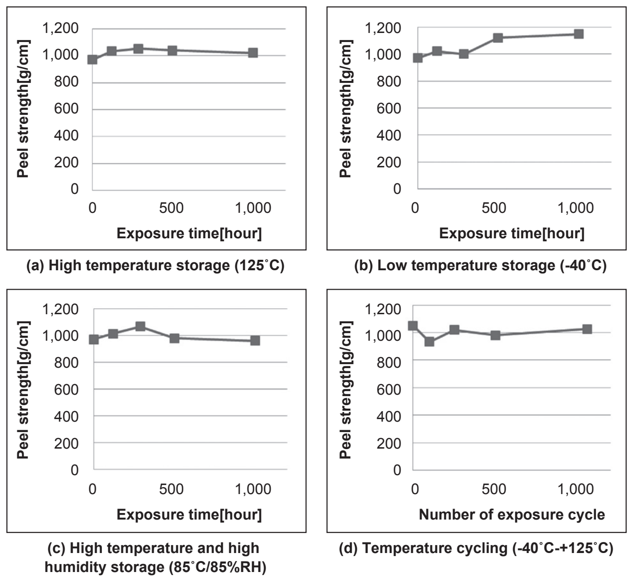


Fig. 4. Reliability for the peel strength of thermal resin

Furthermore, we measured the LED temperature rise before and after each temperature cycling test in the similar manner of section 2-1 and evaluated the reliability of the cooling performance of the new heat diffusion structure. As in **Fig. 5**, the test results show that the cooling performance also remained unchanged before and after being exposed to a temperature cycling test.

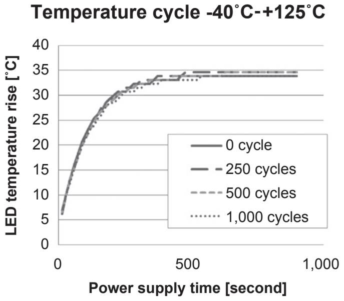


Fig. 5. The reliability of the cooling performance of new heat diffusion structure for temperature cycling test

3. 3-Dimensional structure glued FPC

Conventionally, FPCs have been glued to only flat boards, i.e. a reinforcing board and a cooling heat sink board. We developed a process technique that makes it possible to glue an FPC to a 3-dimensional structure. Examples of trial 3-dimensional structure models are shown in the following Photos.

Photo 2 shows an FPC glued to a thin board-formed base material having a 2.3 mm thickness and 0.5 mm corner radiuses.

Photo 3 shows an LED-mounted FPC glued to a curved surface base material having a 60 mm radius. As the load to LEDs is weak during the gluing process, there is no crack in the soldering of LEDs.

In this way, the new gluing technique makes it possible to glue an LED-mounted FPC to substrate of various shapes.

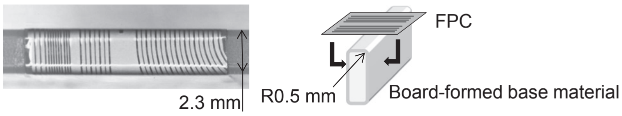


Photo 2. Example of gluing FPC to the board formed base material

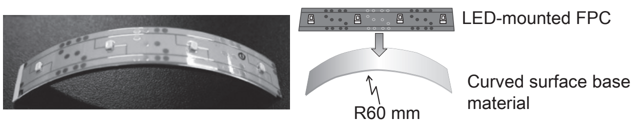


Photo 3. Example of gluing LED-mounted FPC to the curved surface base material

4. Applications to LED lightings

We made it possible to realize an LED module having a wider light distribution without a light reflector or a prism lens by positioning each LED with high directivity in a different direction. **Photo 4** shows a 3-dimensional LED module, which is glued the LED-mounted FPC to a hexagon frustum-formed base made of aluminum, using the new heat diffusion structure of Section 2 and the gluing technique of Section 3. To get a wide light distribution angle, this LED module has an LED on every six slopes, except the top surface, for the purpose of decreasing LED light intensity in the top direction.

Figure 6 shows the light distribution curves calculated for the LED on the flat board and 3-dimensional LED module shown in **photo 4**. **Figure 6 (a)** shows that the light distribution angle of the LED on the flat board is 120 degrees, whereas **Fig. 6 (b)** shows that the one of the 3-dimensional LED module is 240 degrees, and so we make it possible to get a wider light distribution without a light dispersion cover. In addition, we measured the LED temperature of this sample and confirmed that the LED temperature rise was reduced by using the new heat diffusion structure.

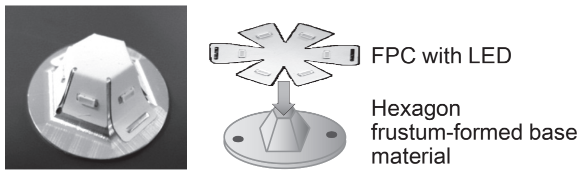


Photo 4. 3-dimensional LED module

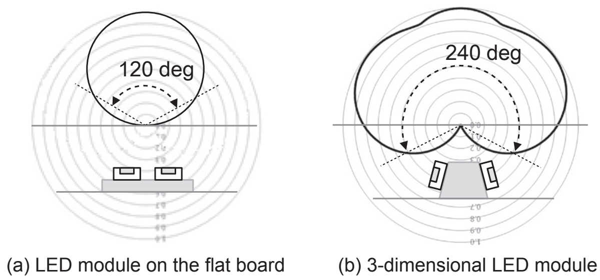


Fig. 6. Calculation result of the light distribution

5. High Output LED Lamp

5-1 Application to a high output LED lamp

Furthermore, to see the possibility to apply the 3-dimensional LED module to a high output LED light by the new heat diffusion structure, we evaluated the temperature rise of high output LEDs (power consumption 3.4 [W], size 2 × 1.6 [mm]) under operating at current of 1 ampere in spite of small size than the LED which we used in Section 2.

Photo 5 shows one of the LED modules in which the FPC with a high output LED is glued to an aluminum board (30 × 30, 50 × 50, 75 × 75 [mm]) using the new heat diffusion structure for evaluations. We hung these LED modules in midair with a thread and evaluated the LED junction temperature risen by the former method in a windless situation. **Figure 7** shows the evaluation results. By decreasing the size of the heat spreading plate, the LED temperature rise increased. However, the LED module on a narrow aluminum board emitted light without damage, even if LED junction temperature increased to around 130 degrees Celsius under operating at current of 1 ampere, so we were able to confirm that this new heat diffusion structure was applicable for the high output LED.

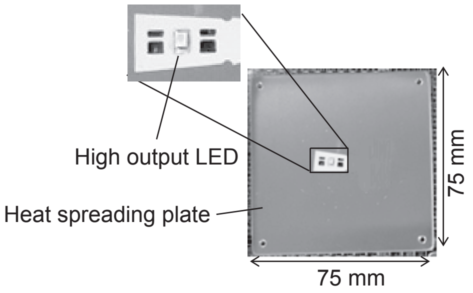


Photo 5. Test module to evaluate the cooling performance for the high output LED

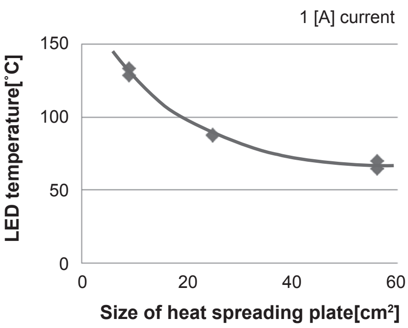
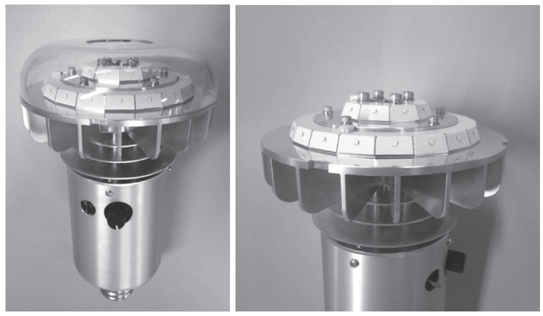


Fig. 7. Evaluation result of the cooling performance for the high output LED

5-2 High output LED lamp

We really designed and manufactured the high output LED lamp. This lamp has 30 high output LEDs, and emits a bundle of rays 10,000 [lm] under operating at electric power 100 [W]. This lamp is shown in **Photo 6**. It comprises of a heat radiation fin and two LED modules. Both LED modules are glued to FPCs with the new heat diffusion structure. The FPCs cover the heat sinks of a 10 frustums-formed base and a 20 frustums-formed base.

While operating this lamp, we confirmed that it emitted a high output and had a wide light distribution. We were able to make a lamp which has high output, lightweight and small size, with a small number of high output LEDs by using the new heat diffusion structure and gluing technique.



(a) Perspective (b) Part of LED modules

Photo 6. High output LED lamp

6. Conclusion

We made it possible to improve cooling performance of an FPC with the new heat diffusion structure, and confirmed that cooling performance was as good as one of metal-PCB. Furthermore, we developed a new technique to glue an FPC to a 3-dimensional substrate. The 3-dimensional LED module manufactured by using two techniques has a wide light distribution of 240 degrees without an optical cover in the calculation. In the future, we expect the application to a high output LED lamp and a lamp for vehicles in addition to general lighting.

Technical Terms

∗1 LED (Light Emitting Diode): A semiconductor device that transforms energy of electrons into light by current injection.

∗2 Light distribution angle: A range of angle that is measured more than a half light intensity from light source all around.

∗3 Temperature-voltage characteristics: The voltage decreases with a temperature rise of the LED.

References

(1) Y. Hosoda, "Development of LED Light Bulbs Having Wide Light Distribution of Over 300 Degrees," Panasonic Technical Journal, 2012, Vol. 58, No. 2, pp. 67-69

(2) T. Ogura, "LED Ceiling Lights featuring Continuous Dimming Control and Color Mixing Functions Contribute to Energy Saving," NEC Technical Journal, 2012, Vol. 7, No. 1, pp. 112-115

(3) M. Kanehiro, "Development of Sumitomo Electric's Flexible Printed Circuit business," SEI Technical Review, 2008, No. 66, pp. 4-18

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