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Optimization of Hybrid LED Package System for Energy Saving Based on Micro Machining Technology and Taguchi Method

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A new concept, 'hybrid LED package system (HLP system)', is proposed as a simpler LED manufacturing process that unifies two steps of the process, the package step and the module step. Moreover, the HLP system can increase optical efficiency by virtue of its integrated optical pattern. A square pyramidal pattern was selected as the basic shape of the pattern of the HLP system. Four shape parameters of the HLP system were selected for optimizing the system. Nine cases of optical simulations organized according to the Taguchi method were performed using LightTools, and the optimum values of the parameters were determined by an SN ratio analysis. Using the optimum values, 28% higher illuminance and 32% higher luminance were predicted simultaneosly compared to the values without the integrated optical pattern. The optimum square pyramidal pattern was machined on a metal mold using an ultra-fine planer and a 90 degree angle diamond tool which would be used as a mold for manufacturing the optimized integrated optical pattern of the HLP system. The exact shape of the square pyramidal pattern with a height of 25 μm and a 90 degree angle was obtained. This study verified that the micro machined mold for manufacturing an optimized integrated optical pattern could be machined accurately, and finally the HLP system with the integrated optical pattern had higher uniform and brighter light distribution.

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NOMENCLATURE

h_x = height of pattern
h_1 = height of dome lens
h_2 = thickness of covered resin
α = angle of pattern

1. Introduction

The LED system has many advantages, but it also consists of four complex manufacturing steps (chip, package, module and system). Each step consists of a few or dozens of processes, which increases the cost and the manufacturing time of LED systems. Since conventional researches[1] focused on only a few processes of a chip step, the effect was relatively small in view of all the manufacturing steps of LED systems from the chip step to the system step. Therefore, a new technology is needed which can innovate the four manufacturing steps.

A hybrid LED package system (HLP system) was newly proposed to solve this problem.[2] The HLP system contains chip-on-board technology that converges the package step and the module step. Since the HLP system also has an integrated optical pattern that controls the direction of light from LED chips and increases optical efficiency, some optical sheets or some optical plates can be removed, which is a process of the system step. Thus, the HLP system consists of only three steps and can decrease the manufacturing cost. An integrated optical pattern can be designed according to the point of use. Even if the pattern is different, the other processes before making the pattern are the same in the HLP system. In this way, the HLP system is fit for mass production. The HLP system was optimized using the Taguchi method for maximizing optical efficiency, and the optimized integrated optical pattern was machined using micro machining technology in this study.

2. Optimization of shape parameters of the HLP system

2.1 Parameter selection

The manufacturing processes of the HLP system consist of chip bonding, wire bonding, dome lens dispensing and injection molding. Since the technologies for chip bonding and wire bonding directly on printed circuit board (PCB) belong to chip-on-board technology, they are already settled. However, the other two processes should be developed.

There has been no design guide for the HLP system including the dome lens and the integrated optical pattern. We selected a square pyramidal pattern as a basic shape of the pattern. The square pyramidal pattern is known to increase optical efficiency and is expected to have a wider viewing angle than prism film[3] because it is an overlapped pattern of X-axis and Y-axis prism patterns. Four shape parameters, the height of the pattern (h_x), the angle of the pattern (a), the height of the dome lens (h_1) and the thickness of the covered resin (h_2) were selected for optimizing the HLP system as shown in Fig. 1. The diameter of the dome lenses were fixed at 4mm which is the proper value for covering an LED chip and electrodes on PCBs. The four shape parameters were related to the dome lens dispensing process and injection molding process. The spacing between LED chips was 25 mm which is similar to the value of the commercial direct type of LED BLU (Backlight Unit). In addition, the values of the height of the pattern and the angle of the pattern were based on the commercial optical films for LED BLU.

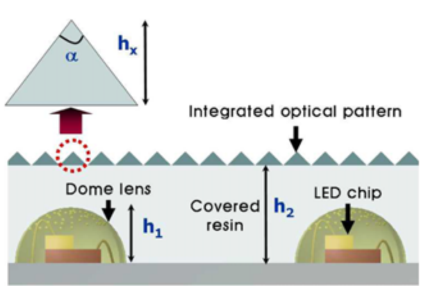


Fig. 1 Four shape parameters of the HLP system

Table 1 The parameter conditions of optical simulations based on the L9 orthogonal table (Normalized illuminance and luminance)

No.	h_x (μm)	α (°)	h_1 (mm)	h_2 (mm)	Illuminance (%)	Luminance (%)
1	25	90	1.0	3	127.4	132.7
2	25	60	1.5	2	122.2	123.5
3	25	120	0.5	4	127.8	109.7
4	50	90	1.5	4	126.3	130.5
5	50	60	0.5	3	122.4	123.3
6	50	120	1.0	2	130.0	110.2
7	75	90	0.5	2	127.3	132.5
8	75	60	1.0	4	122.2	123.9
9	75	120	1.5	3	129.0	108.9

2.2 Optimization based on the Taguchi method and optical simulation

Three levels of each parameter were determined and arranged according to the L9 orthogonal table of the Taguchi method as shown in Table 1. Eighty one cases should be examined if three levels of four parameters were fully arranged, however, only nine cases were examined using the Taguchi method.

The optical simulations of the nine cases were performed using LightTools software. The HLP system was designed to have six high power white LED chips with a size of 1 mm*1 mm spaced 25 mm apart. The optical properties of dome lenses and covered resin were assumed to be the same as the candidate resins which will be used in mass production. The optical simulation without the integrated optical pattern on the covered resin was also performed in order to verify the effect of the pattern.

The effect of the integrated optical pattern is displayed in Fig. 2, which is one of the nine optical simulation results. It was observed qualitatively that the pattern increased the light uniformity near the LED chip. The pattern also increased the average illuminance over 22% and the average luminance over 23.5% quantitatively in this case. Better uniformity and higher illuminance and luminance were observed in other cases, too.

The Taguchi method determines the optimum values of each parameter using the SN ratio (Signal-to-Noise ratio).[4] Generally, a larger signal and smaller noise is the best, so that the largest SN ratio yields the optimum results. The SN ratio is calculated according to the characteristics of the output properties, which are 'the-smaller-the-better type', 'the-larger-the-better type' and 'on-target type.' Since the output properties of this research are illuminance and luminance, 'the-larger-the-better type' should be applied. The SN ratio of this type can be calculated as

$$SN = -10\log\left[\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_1^2}\right], \tag{1}$$

where y is the number of all the data points and y_i is the ith value of the illuminance or the luminance.

The SN ratios of the four shape parameters are presented in Fig. 3. The optimum values of α were not the same in the two cases (average illuminance and average luminance) and SN ratio varied significantly, which meant that α has the highest effect on illuminance and luminance. The optimum values were 120 degrees and 90 degrees, respectively. Luminance means the sum of light only to the vertical direction; a 90 degree angle, which concentrates light to the vertical direction, is better than a 120 degree angle, which scatters light. This is

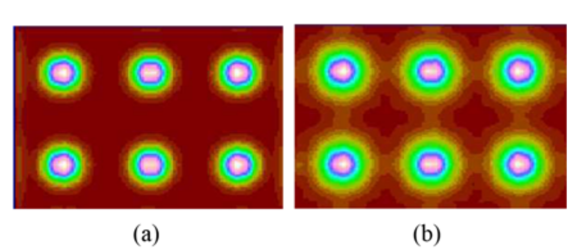


Fig. 2 Illuminance distribution of the HLP system (a) without an integrated optical pattern and (b) with an integrated optical pattern

the reason why the prism sheet with 90 degree patterns is widely used in display industries for enhancing luminance.[5] Illuminance includes the light to the vertical direction and the inclined direction because it means the total light on a certain surface. Thus, illuminance is dependent on the total light from the light system. A smaller angle of pattern produces less light due to more total reflection, so that the SN ratio of a smaller angle in case of is lower. Though 120 degrees is the optimum value for illuminance, an SN ratio value of 90 degrees is also high. Therefore, 90 degrees was selected as the optimum value for illuminance and luminance.

Though the SN ratios indicated different values of h_x for the optimum value, the variation of the SN ratios of h_x was very small. A previous research showed the average luminance was relatively uniform in the range of 10 µm to 50 µm.[6] This range is similar to the range of h_x in this study. Therefore, we can choose any value of h_x, and 25 mm was selected for the optimum value. The optimum values of h_1 and h_2 were the same in the two cases, which were 1.0 mm and 2 mm, respectively. The thickness of covered resin (h_2) is directly related to the amount of absorption of light, so that the smallest value is good for enhancing luminance and illuminance. Furthermore, the smallest value of h_2 is good for mass production because a 2 mm thickness needs the smallest amount of resin.

Based on the results above, 25 mm, 90 degrees, 1.0 mm and 2 mm were determined as the optimum values for the height of pattern (h_x), the angle of pattern (a), the height of dome lens (h_1) and the thickness of the covered resin (h_2), respectively.

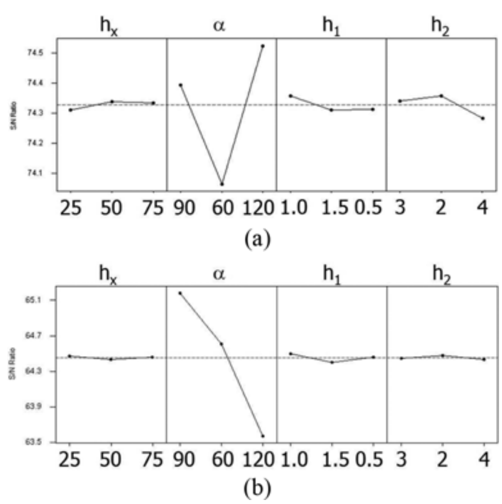


Fig. 3 SN ratio values of four shape parameters for (a) illuminance and (b) luminance

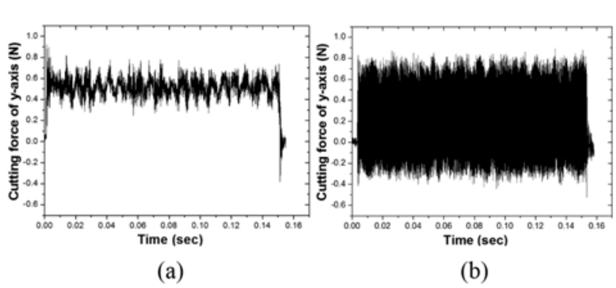


Fig. 4 Cutting force of (a) the first machining step and (b) the second machining step (after rotating the diamond tool)

The average illumination and the average luminance of the HLP system having the optimum shape parameters were predicted by the Taguchi method. Finally, 28.1% higher illuminance and 32.5% higher luminance were obtained simultaneosly compared to those without an integrated micro optical pattern. Our results proved that the integrated micro optical pattern could increase optical efficiency by about 30%.

3. Micromachining of a metal mold for integrated optical patterns and verification of light distribution

A metal mold was machined based on the optimization in order to manufacture the optimized integrated optical pattern of the HLP system. An ultra-fine planer (UVM350, Toshiba Machine) was used for the micro machining, which had repeatability of 10nm and XYZ axis strokes of 400 mm, 400 mm and 200 mm. A single-crystal diamond tool with a 90 degree angle was used. The machined height was set at 25 mm which was matched the optimum level of h_x. Six pass machining of 10 mm, 7 mm, 5 mm, 3 mm, 2 mm and 1 mm (3 mm over-depth) was applied. The over-depth machining can increase the quality of the machined surface.[7] The feed rate was 200 mm/s. The diamond tool was rotated 90 degrees and machined by the same multi-pass machining again to make the square pyramidal shape after the first machining step.

If the relative height between the diamond tool and the metal mold is different before and after rotating the tool, there should be a line at the apex of the square pyramidal patterns. The long line at the apex makes the height of the pattern lower than designed and can induce asymmetry light distribution. Therefore, it should be checked whether the lines exist at the apex after machining the square pyramidal patterns.

The cutting force of the first machining step and the second machining step showed different shapes. The amplitude of the cutting force at the second machining step was much larger than the one at the first step as shown in Fig. 4. The reason was probably that the diamond tool periodically touched and untouched the prism patterns machined at the first machining step while the diamond tool touched the metal mold continuously at the first machining step. If the expectation was right, the feed rate calculated by the data of Fig. 4(b) should be the same as 200 mm/sec which was set at experimental conditions. The cutting force of the second step was a constant sinusoidal graph whose period was about 0.00026 sec. The pitch of the patterns was 50 mm, and the

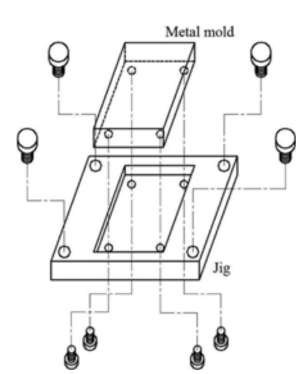


Fig. 5 A schematic diagram of the ‘double-constricted jig’

calculated feed rate was about 200 mm/sec. This meant our expectation was right.

Much larger amplitude and periodical change could make severe vibration in the machining system and the machined surface would have high roughness. Therefore, a much more robust system is essential for machining the square pyramidal patterns than for machining the prism patterns. The jig for holding the metal mold was very important for preventing the vibration. We made a 'double-constricted jig' as shown in Fig. 5. The metal mold was fixed on the jig tightly by four screws and the jig was also fixed on the machining stage tightly by four other screws.

The final machining result is presented in Fig. 6. There was no burr on the surface and a very short line at the apex. These mean that there was no vibration effect during the second machining step and the uniform relative height between the diamond tool and the metal mold was maintained before and after rotating the diamond tool. Therefore, a good quality of machined surface and exact shape of square pyramidal pattern having 25 mm height (50 mm pitch) and 90 degree angle were obtained. We verified that the micro machined mold for manufacturing the optimized integrated optical pattern was machined accurately.

An HLP system was manufactured using the machined metal mold and verified the optical effect of the integrated optical pattern as shown in Fig. 7. The light distribution of Fig. 7(a) and Fig. 7(b) was similar to the light distribution of Fig. 2(a) and Fig. 2(b). Much more uniform light distribution was observed in virtue of the integrated optical pattern. Moreover, large dark zone was observed at the HLP system without the integrated optical pattern, however, the dark zone turned to be brighter at the HLP system with the integrated optical pattern.

4. Conclusions

We proposed a new concept for the hybrid LED package system, optimized the shape parameters of the HLP system, including the integrated optical pattern and machined micro mold having the optimized pattern. We made the following conclusions:

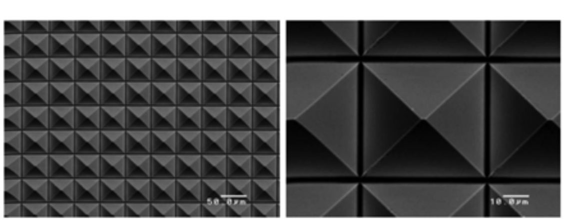
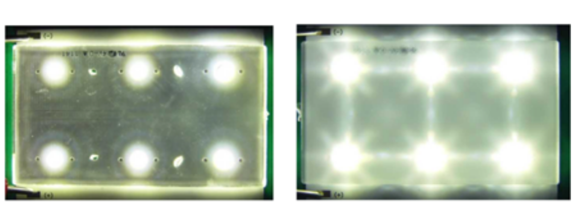


Fig. 6 The final machining results of the square pyramidal patterns



(a) (b)

Fig. 7 Light distribution of the HLP system (a) without an integrated optical pattern and (b) with an integrated optical pattern

(1) Four shape parameters: the height of pattern, the angle of pattern, the height of dome lens and the thickness of the covered resin were optimized by the Taguchi method and optical simulation. Their optimum values are 25 mm, 90 degree, 1.0 mm and 2 mm, respectively.
(2) The square pyramidal pattern with a height of 25 mm and a 90 degree apex were successfully machined by machining prism patterns (the first machining), rotating the diamond tool 90 degrees and machining prism patterns again (the second machining step).
(3) The HLP system with the integrated optical pattern showed higher uniform and brighter light distribution than without the pattern.

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