Effects of laser micro-machining on LED’s luminous performance

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Abstract: The microstructure was fabricated on LED surface with a picosecond laser. The measurement of far field light distribution from processed LED agrees with the simulation. Such fabrication may have potential application for LED light distribution.

1. Introduction
Laser processing technology has rapidly developed recently. By focusing the laser to sub-micron level, a small area of processing can be achieved, which plays a great role on integrated technology and other industries with high precision requirements[1]. On the other hand, LED, as a typical representative of the semiconductor light source, has plenty of good performances, such as light weight, high brightness, environmental protection, long lifetime and so on[2]. It gradually replaces the traditional light source and becomes the new generation of lighting. Laser processing technology can be used to process microstructure in LED’s packaging materials in order to achieve LED’s secondary light distribution and satisfy the lighting needs of different environments.

2. Fabrication

A triangular lattice periodic arrangement [Fig-1] is designed to adjust the LED light, so that the luminous range is more concentrated and the light field is more soft. The center of two holes is 80um. The radius of each hole is 30um. In experiment, the laser was a high energy picosecond Nd: YAG laser system with a repetition rate of 10 Hz, a bandwidth of 20 ps, a single pulse energy of about 0.22 mJ, and an exposure time of 8s for each individual microstructure. Through electron beam scanning microscope, the processed microstructure [Fig-2] shows some differences compared with the designed one. The overall arrangement is neat, but each individual microstructure is not a regular circular aperture, which is limited by experimental conditions and experimental methods. 3D microscope was used for further observation. The image [Fig-3.(a)] shows only one row of the whole structure. So it’s speculated that on a more microscopic scale, each row of the fabric is not at the same depth. In addition, each single microstructure is just about a quarter of a circle. Presumably it’s caused by the uneven distribution of laser spot energy and the target face’s not strictly placed vertically. The radius of a single microstructure is measured as 20.311um [Fig-3.(b)], which is smaller than our expectation, but in fact it is not entirely accurate because it is only an estimate.
3. Measurement

Divergence angle and luminous efficiency are key parameters of LED light field distribution. The divergence angle represents the luminous range of LED, and the luminous efficiency is defined as the luminous flux divided by the input power. The two parameters can be measured with an optical power meter, integrating sphere and other instruments. It was found that the divergence angle of the original LED was 174° while that of the processed LED was 166° [Fig-4.(a)]. The divergence angle of LED reduced by 8° after the micro-structure array is processed, which indicates that the modulated light field distribution becomes more concentrated. In addition, at the same input voltage (more than 15V), the luminous efficiency of the processed LED also reduced [Fig-4.(b)], which declares that the luminous flux of processed LED is reduced, so the light intensity is reduced and the light field gets more soft. It is interesting to note that the processed LED still achieves maximum luminous efficiency at an input voltage of 16V, indicating that its optimum operating voltage does not change.

4. Simulation

The theoretical simulation analysis was performed with the software Virtual-lab. In the simulation, the far-field light of the partially coherent light is used as the light source. In order to simulate the actual light source better, the light source is set to five wavelengths with specific intensity ratio [Tab-1], which is determined by the actual spectral analysis. The effect of the microstructure of the LED’s surface on its outgoing light is equivalent to the modulation of the grating. So a double interface grating is used as a grating with the two interface thickness of 1um. The grating is provided with a periodic
arrangement of the tapered structure whose top is cut. A single unit’s diameter is 60um and every two units are separated by 80um.

<table>
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<th>600</th>
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<td>0.7</td>
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Tab.1. Parameter setting for wavelength of light source

The far field lights, which are modulated or not modulated by grating, are tracked. At the same distance, the diameter of the light spot without modulation is about 16mm while that of the modulated one is about 14mm. It clearly shows that the spot range decreases after the grating modulation[Fig-5.(a),(b)], which is consistent with the experiment result that light distribution becomes more concentrated. Besides, the color of the image given by the simulation reflects the center wavelength of the light field. After modulation, the center wavelength shifts to the short wavelength area. The visual effect is not as bright as the original.

Fig. 5. (a) far field light distribution without modulation. (b) far field light distribution with modulation

5. Conclusion
In order to enhance the effectiveness of the results, we also processed a sample of which the microstructure is periodic quadrilateral lattice arrangement. The changes of divergence angle and luminous efficiency were the same. Although the processing parameters and simulation settings need to be further optimized, the simulation and experimental results are consistent, indicating that our design is effective and the fabrication method also plays a certain role.

6. References