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Micro-machining and optical characterization of randomly distributed micro-lens array

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Abstract

Linear micro-patterns (eg. prism pattern) have been widely used in display industries for enhancing light efficiency. However, the patterns are seen from the outside of ultra-thin displays (especially smartphones and tablet PCs) by users. Their linear-shape and regularity are the main causes of this problem. Randomly distributed dot-type micro-patterns can solve this problem. We developed a code to design randomly distributed micro-lens arrays, machined the array and characterized its light-diffusing effects. The developed code automatically calculated the coordinates of the micro lenses which were not overlapped on each other and had no regularity considering the radius and the number of the lenses. The designed array was machined on a 64brass mold by the micro indentation machining technology and a self-developed machining system. The micro indentation machining technology is similar to the indentation hardness test and thus it is a simple and low-cost machining method. The shape of the machining tool was parabolic vertically and a little ellipsoidal horizontally. The average radius and the number of the machined micro lenses were about 11.9μm and more than 80000ea, respectively. The machining area was 10mm×10mm. The machined lenses were located perfectly consistent to the calculated coordinates. A transparent film was molded using a UV-curable resin for characterization of the machined randomly distributed micro-lens arrays. The spot size of a transmitted green laser was compared to the original size. The light-diffusing area was enlarged about twelve times than the original area, which meant the machined array showed excellent light-diffusing effects. Therefore, it is verified that the randomly distributed micro-lens arrays can be machined by the micro indentation machining technology and the machined arrays can diffuse the light excellently in this study.

Keywords: Micro-machining, Indentation machining technology, Randomly distributed pattern, Micro-lens array, Light-diffusing

1. Introduction

A liquid crystal display (LCD) needs light sources and optical components because it can not emit light by itself. The optical components concentrate or diffuse lights emitted from the light sources. The diffusion is more important in the recent time because a LCD is much thin. Linear micro-pattern widely used for concentrating the lights can not meet this demand, moreover, the linear pattern is seen from the outside of ultra-thin display. Their linear-shape and regularity are the main causes of this problem. A randomly distributed dot-type micro-lens array is supposed to replace the linear micro-pattern. Therefore, we developed a new code to calculate the coordinates of the array, machined the array using micro indentation machining technology, and verified its light characteristics in this study.

2. Design of randomly distributed micro-lens array

Micro lenses were distributed regularly in general micro-lens arrays [1-3]. In this case, coordinates of all micro lenses can be calculated simply by determining the distance between two micro lenses (pitch). However, the pitch is not constant but random in a randomly distributed micro-lens array. We developed a MATLAB code to calculate the coordinates of randomly distributed micro lenses considering the radius and the number of the micro lenses. Using the developed code, we designed a micro-lens array to have 12.5μm radius and more than 80,000 lenses on 10mm*10mm area in this study. Figure 1 shows that the calculated micro-lens array had no regularity and no micro lenses to be overlapped on each other.

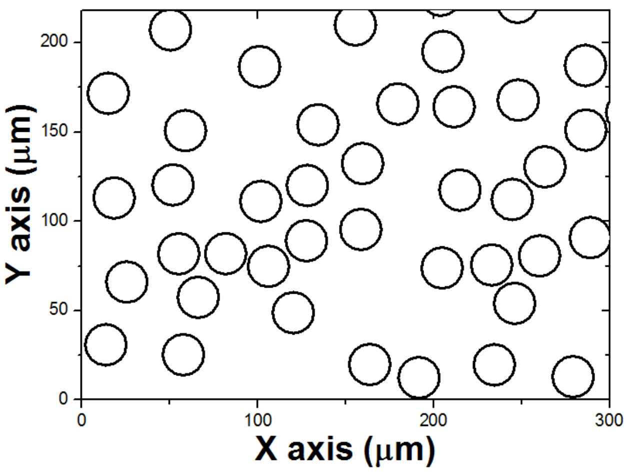

Figure 1. An example of randomly distributed micro-lens array

3. Micro indentation machining

Micro indentation machining technology was originated from instrumented indentation test which measures mechanical properties of small materials [4, 5]. An indenter (a tool) pushes a material (a metal mold), and a residual indentation (a micro lens) is generated. The machining process is much simple and needs low-cost. Since general indentation testers have low speed to make indentations, we developed a new micro indentation machining system using a solenoid actuator as shown in Fig.2. The average speed was about 6Hz.

The designed randomly distributed micro-lens array was machined on a 64 brass mold. The shape of a machining tool was parabolic vertically and a little ellipsoidal horizontally. The tool was made of single crystal diamond. It took about four hours. The randomly distributed micro-lens array was successfully machined as shown in Fig. 3. They had no regularity and were not overlapped on each other. The machined lenses were located perfectly consistent to the calculated coordinates. The average radius of the machined micro lenses was about 11.9μm.

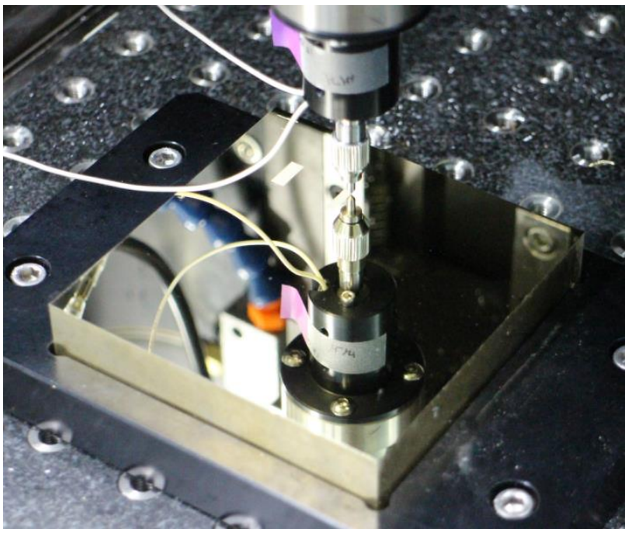

Figure 2. A newly developed micro indentation machining system for machining micro-lens arrays

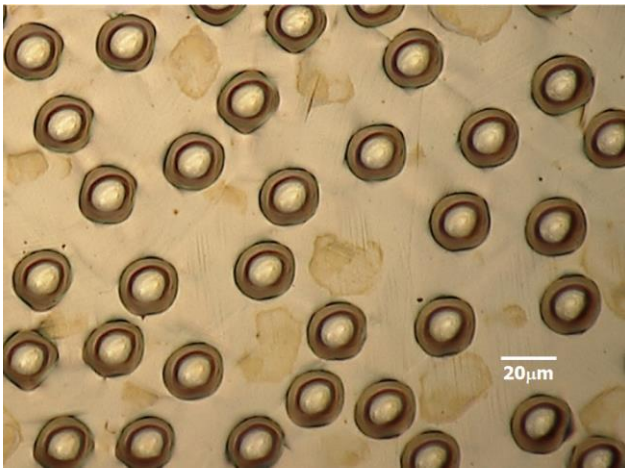

Figure 3. A machined randomly distributed micro-lens array on 64 brass mold

4. Optical characterization

The machined array was replicated on a transparent film using a UV-curable resin for optical characterization. Since the diffusion was important, we measured the spot size of transmitted green laser through the transparent films with the randomly distributed micro-lens array and with no pattern. As shown in Fig. 4, the transparent film having the randomly distributed micro-lens array diffused a green laser spot widely. The radius of the spot size was enlarged about three and half times, which meant the diffused area was more than twelve times than the area of the original spot. Since laser has high straightness, this means that the randomly distributed array can diffuse light effectively in ultra-thin display which uses Lambertian LEDs as a light source. Therefore, it is verified that the randomly distributed micro-lens arrays can be machined by the micro indentation machining technology and the machined arrays can diffuse the light excellently in this study. The degree of randomness seems to be a main factor to control the spot size, and this will be discussed in a later paper.

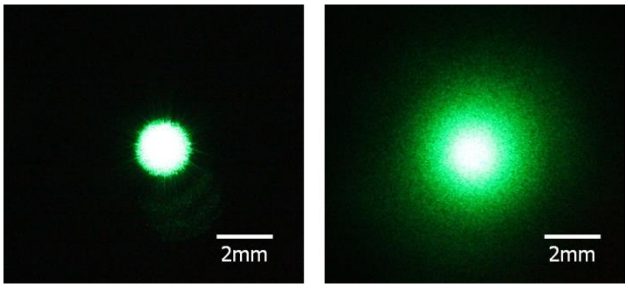

Figure 4. The spot areas of transmitted green laser through (a) no pattern and (b) randomly distributed micro-lens array

5. Conclusions

We suggested a randomly distributed micro-lens array for replacing linear micro-patterns in ultra-thin displays in this study. We developed a new code for designing the array considering the radius and the total number of the micro lenses and machined the designed array using micro indentation machining technology. The average radius and the total number of the machined micro lenses were 11.9μm and more than 80000ea, respectively. The replicated array on a transparent film diffused a green laser spot more than twelve times larger area. This meant the suggested randomly distributed micro-lens array could be used for diffusing lights in ultra-thin displays. We will adapt this random array to real ultra-thin displays in the future.

References

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