Optical simulation of micro-pyramid arrays for the applications in the field of backlight unit of LCD

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Abstract

Optical performances of micro-pyramid arrays were simulated by ray tracing technique for the application of backlight unit of LCD. The angular distribution of the luminance and the on-axis luminance gain depended on the apex angle, the refractive index, and the density of micro-pyramids. The on-axis luminance reached a maximum when the apex angle was 90°. It also increased as the density and the refractive index of micro-pyramids increased. The present result showed that highly-efficient optical sheet might become realized by adopting micro-pyramid array and corresponding development of manufacturing processes.

1. Introduction

Rapid growth of the world market of flat panel displays pushes all display manufacturers innovate their technologies for improving both the device performances and the cost competitiveness. In case of liquid crystal display(LCD), the backlight unit(BLU), which supplies LCD with appropriate white light, has become one of the key components for the technological innovation[1]. BLU consists of many parts such as the light source, light guide panel for edge-lit type BLU, diffuser plate for direct-lit type BLU, several optical sheets, mold frame, driving circuits, etc. Among them, optical sheets are used to manipulate the angular distribution of light output of BLU and thus to increase the on-axis luminance. However, since the optical sheets occupy main portion of the total cost of BLU, it is highly desirable to develop hybrid sheets of new concepts in order to reduce the number of optical sheets and thus to reduce the cost of BLU.

As a try to achieve the above goal, the present contribution reports the simulation results on the optical performances of micro-pyramid array, which might be one of the candidates for replacing the present combination of diffuser sheets and/or prism sheets. Ray tracing technique using the ASAP software(Breault Research Org.) was adopted for the simulation. The density, the apex angle, the refractive index of micro-pyramids have been systematically changed to investigate the optical performances of the microlens arrays. From the simulation results the distribution of the light output from the micro-pyramid array in addition to the on-axis luminance gain has been obtained under various conditions and compared to one another.

2. Results

Micro-pyramids of which the basal area was 60*60 μm^2, were designed on a plate with a thickness of 125 μm, an area of 5.94*5.94 mm^2, and a refractive index of 1.5. Total number of micro-pyramids on the plate was 9801. Figure 1 shows a schematic drawing of part of the micro-pyramids array. This array was put on a virtual Lambertian light source, and the output angular distribution of the luminance on the array was monitored. Below the array, a perfect mirror reflector was put for recycling the light reflected from the surfaces of the micro-pyramid array.

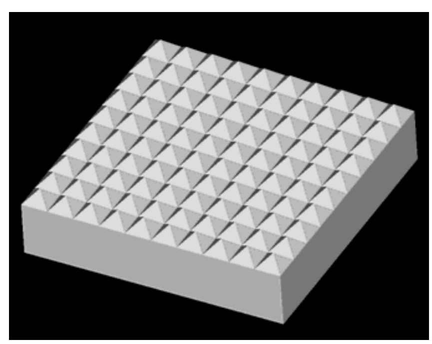

Figure 1. A schmatic drawing of part of the simulated micro-pyramids array.

2.1 The effect of the apex angle

The apex angle of micro-pyramids were changed between 70 and 110°. The apex angle of the micro-pyramids was changed by adjusting their heights while maintaining the basal area to 60*60 μm^2. Figure 2 shows the dependence of the luminance on the viewing angle when the refractive index of micro-pyramids was fixed to 1.55 and the density was maximum. For comparison, the Lambertian distribution emitting from the virtual light source was also included. As the apex angle of micro-pyramids deviates from 90^o, the angular distribution of the light output becomes wider and the on-axis luminance gain decreases. This is consistent with the result obtained from the conventional prism sheet[3]. We can also observe side lobes located at high angles, similar to the case of conventional prism sheet.

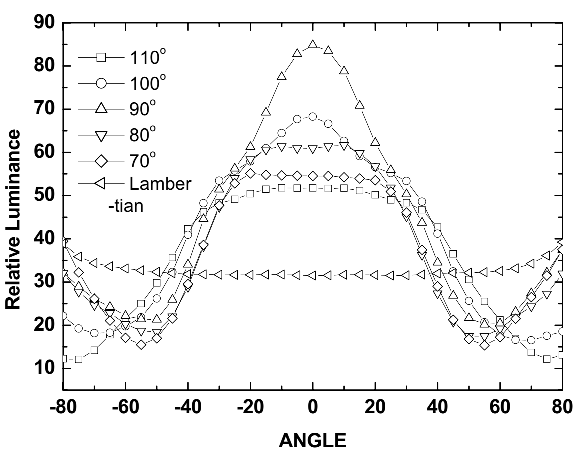

Figure 2. The dependence of the luminance on the viewing angle simulated at various apex angles.

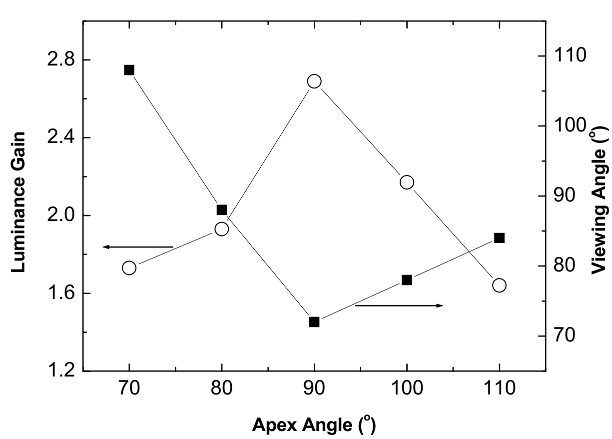

Figure 3. The dependence of the luminance gain and the viewing angle on the apex angle.

Figure 3 exhibits the gain of the on-axis luminance compared to that of the Lambertian distribution that was set to 1. As the apex angle approaches 90^o from both high- and low-angle sides, the relative luminance increases. At the value of 90^o, the on-axis luminance gain is approximately 2.7. This value is larger than the on-axis luminance gain of approximately 2 obtained from the simulation result carried out on the conventional prism sheet having an apex angle of 90^o. The viewing angle, defined by the half width at half maximum of the luminance distribution, becomes minimum when the luminance gain is maximum.

2.2 The effects of the refractive index and the density

Figure 4 shows the relative luminance depending on the viewing angle at several refractive indices. As can be expected from the Snell's law, the ray entering the inclined surfaces of micro-pyramids within a certain range of angles from below will be refracted towards the LCD more directly, resulting in a higher on-axis luminance. The viewing angle decreases with increasing refractive index. The viewing angle and the luminance gain are plotted as a function of the refractive index in Figure 5.

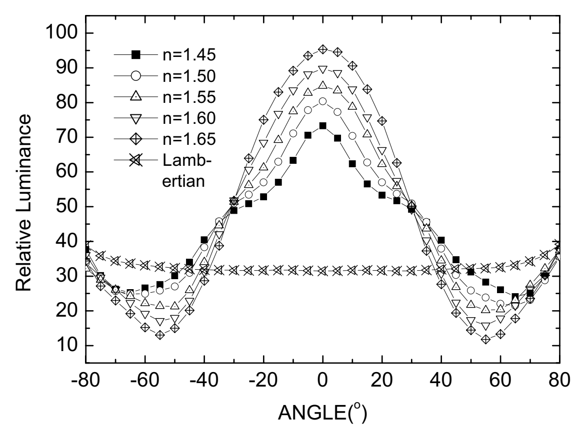

Figure 4. The dependence of the luminance on the viewing angle simulated at various refractive indices.

As a next step, the distance between each micro-pyramid was adjusted to change the density of the micro-pyramids on the substrate. Figure 6 exhibits the dependence of the relative luminance on the viewing angle at several densities. 100% denotes the case when there is no distance between micro-pyramids.

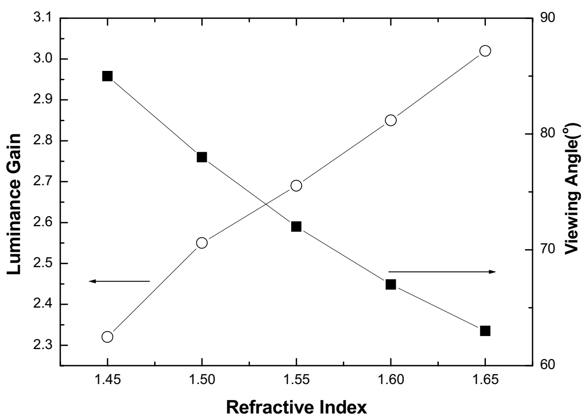

Figure 5. The dependence of luminance gain and viewing angle on the refractive index.

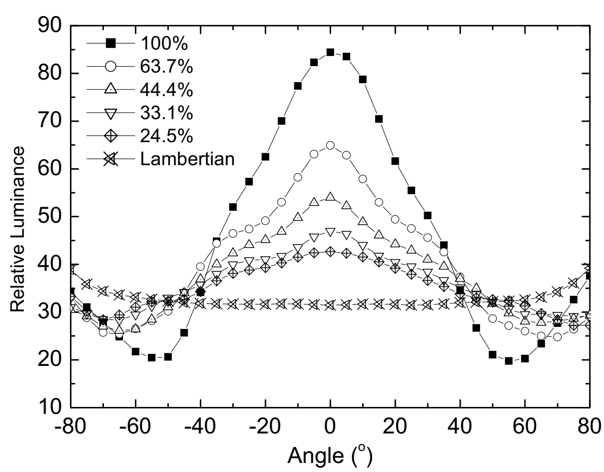

Figure 6. The dependence of the luminance on the viewing angle simulated at various densities of micro-pyramids.

As the density decreases, the luminance distribution approaches the Lambertian distribution, and the luminance gain decreases linearly. This results means that the luminance profile and the on-axis luminance gain can be adjusted by changing the density of micro-pyramids. Figure 7 shows the viewing angle and the luminance gain as a function of the density. These two quantities are inversely proportional to each other.

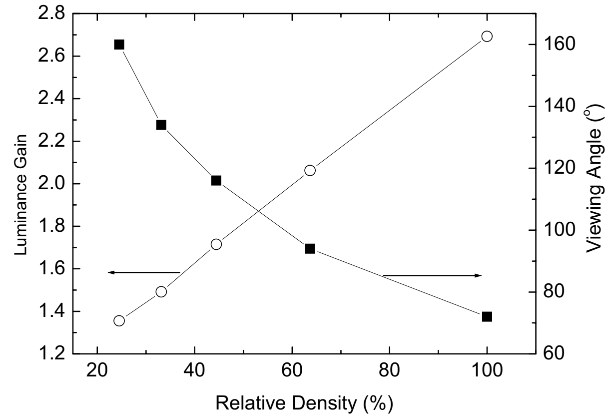

Figure 7. The dependence of luminance gain and viewing angle on the density of micro-pyramids.

2.3 The effect of cutting the micro-pyramids

In order to investigate the effect of modification of micro-pyramids, the apex portion of micropyramids having an apex angle of 90° was cut at a certain height. Therefore, the cut micro-pyramids have a flat area on the top, and the angle of the inclined surface is fixed to 45°. The luminance distribution was investigated as a function of the height of these reshaped micro-pyramids.

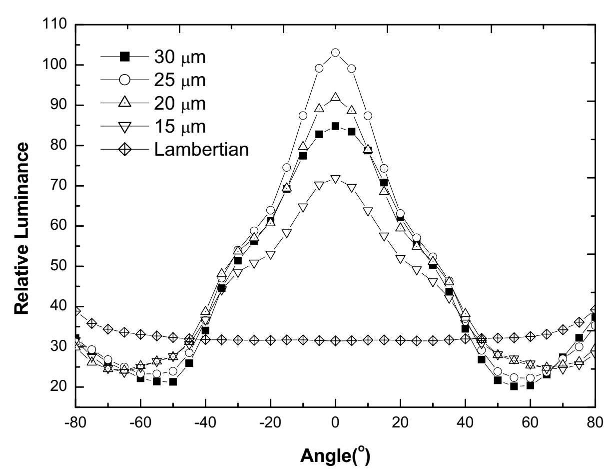

Figure 8. The dependence of the luminance on the viewing angle simulated at several reshaped micro-pyramids. The numbers denote the height of the cut micro-pyramids.

Figure 8 shows the angular distribution of the relative luminance as a function of angle at several heights of the reshaped micro-pyramids. The symbol for the height of 30 μm corresponds to the uncut, original micro-pyramid array. Interestingly, the luminance distribution becomes sharper and the on-axis luminance increases as the height decreases from 30 to 25 mm. Upon further decreasing the height, the on-axis luminance decreases than the case of original micro-pyramid array. Figure 9 exhibits the dependence of luminance gain and the viewing angle as a function of height of the cut micro-pyramids. The luminance gain becomes maximum at a height of ~ 25 μm with a minimum viewing angle.

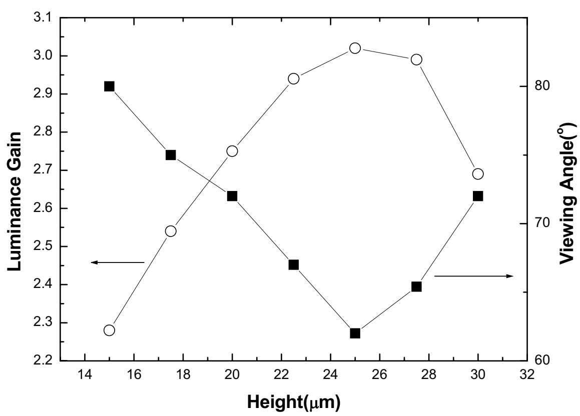

Figure 9. The dependence of luminance gain and viewing angle on the height of the cut micro-pyramids.

2.4 The effect of randomization of the micro-pyramid array

The periodicity of micro-pyramids will interfere with the periodic arrangement of pixels of liquid crystal display resulting in undesirable Moiré patterns[4]. In order to reduce Moiré patterns, it is necessary to randomize the locations of micro-pyramids. Randomized micro-pyramid arrays were simulated at the relative densities of 78.5, 50.3, 34.6 % and compared to the results of periodic arrays at the same densities. Overlapping between micro-pyramids was not allowed in the randomized array. The angular distributions and on-axis luminance gains of all cases showed exactly the same behaviors. Therefore, to randomize the locations of micro-pyramids would be one solution for reducing the undesirable Moiré patterns.

3. Conclusion

The present simulation results show that optical performances of the micro-pyramid array, that is, the angular distribution of the luminance and the on-axis luminance gain can be controlled by adjusting the density, the apex angle, the refractive index and the reshaping condition of the micro-pyramids. The luminance gain showed a maximum at the condition of the apex angle of 90^o, the refractive index of 1.65, the maximum density, and the height of 25 μm of cut micro-pyramids. The light-gathering performance represented by the luminance gain of the micro-pyramids under these best conditions was much superior to the conventional prism sheet.

However, periodic structure in the optical sheet may interfere with the pixel structures of the LCD panel resulting in the undesirable Moiré pattern. It has been shown that to give randomness to the positions of the micro-pyramid array at the same density provided the same optical performances.

Present study shows the possibility of developing a new kind of optical collimating sheet which might replace the expensive conventional sheets. The manufacturing processes for the mass production of the special micro-structures of microlens arrays including the randomization of their positions should be developed for successful commercialization, which seems to be another research topic in this field.

4. Acknowledgements

This work was supported by the Research Grant of Hallym University.

5. References

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