

Effects of Reshaping Micro-pyramids and Prisms on the Optical Performances of Light Collimating Films in the Field of LCD Backlight

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ABSTRACT

Optical performances of micro-pyramid arrays and one-dimensional micro-prisms were simulated by ray tracing technique for the application of backlight unit of LCD. The angular distribution of the luminance was investigated as a function of several parameters such as the apex angle, the refractive index, and the density. The on-axis luminance reached a maximum when the apex angle was 90° in both cases. It also increased as the density and the refractive index increased. The effects of reshaping, in particular, cutting the apex region on the optical performances were investigated, and found that the angular distribution of the luminance around the on-axis direction became much sharper than the uncut cases.

INTRODUCTION

Competition between flat panel displays (FPDs) drives panel 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 of LCD. Among various components comprising BLU, optical sheets play the role of homogenizing the white light from light sources and manipulating the angular distribution of light output in order to increase the on-axis luminance accompanied by acceptable viewing-angle performances. It is thus very important to optimize optical sheets for achieving better device performances of BLU. In addition, 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.

Micro-lens sheets including prism sheets are used to enhance the on-axis luminance via refraction of rays on the surfaces of micro-lenses. Recently, several micro-lens sheets and modified prism sheets have appeared in the market or have been presented[1]. The luminance gain of these sheets is determined by several design parameters of micro-lenses and also material parameters

comprising the substrate and the micro-lenses on it. The present contribution is devoted to our simulation results on the optical performances of micro-pyramid arrays[2] and one-dimensional prism arrays formed on a substrate. The effects of reshaping micro-lenses, in particular, cutting the apex region of micro-pyramids and micro-prisms on the optical performances will be discussed. The results will be compared to the characteristics of the light output from the uncut micro-pyramid array and micro-prism array under various conditions.

SIMULATION

Simulation method

Ray tracing technique using the ASAP software(Breault Research Org.) was adopted for the simulation. Preliminary results about the effects of the density, the apex angle, the refractive index on the optical performances of the micro-pyramid array have been reported elsewhere[2].

Micro-pyramid array

Micro-pyramids, of which the basal area was $60 \times 60 \mu\text{m}^2$, were arrayed on a plate with a thickness of $125 \mu\text{m}$, an area of $5.94 \times 5.94 \text{ mm}^2$, and a refractive index of 1.5. Total number of micro-pyramids on the plate was 9801. This sheet 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. In order to investigate the effect of modification of micro-pyramids, the apex portion of each micro-pyramid having an apex angle of 90° was cut at a certain height. Therefore, the cut micro-pyramids have a flat area on their top, and the angle of the inclined surface with respect to the substrate is fixed to 45° .

Micro-prism array

One-dimensional micro-prisms were arrayed parallel on a substrate of which the properties were the same as that used for the micro-pyramid sheet except the substrate area, which is $30 \times 30 \text{ mm}^2$ in this case. The pitch and the apex angle were $60 \mu\text{m}$ and 45° , respectively. As has been done on

micro-pyramids, the apex portion of each micro-prism was cut at a certain height. The other simulation conditions were the same as those of micro-pyramid arrays. Figure 1 represents one example of cross-sections of the modified micro-pyramids or prisms simulated in this study.

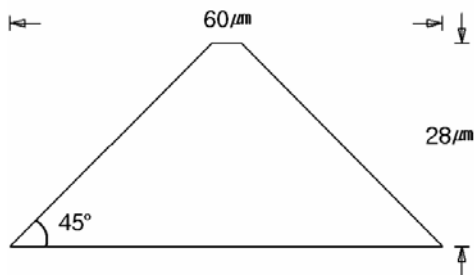


Fig. 1 A cross-section of cut pyramid or prism whose height is 28 μm .

RESULTS

Cut micro-pyramid sheets

Optical performances of the uncut micro-pyramid array are determined by several parameters such as the apex angle, refractive index, and density of micro-pyramids[2]. The on-axis luminance increases as the refractive index and the density increase. The optimum apex angle for highest optical gain is 90° , which is the same condition of conventional prism sheets[3]. In order to investigate the effect of modification of micro-pyramids, the apex portion of micro-pyramids having an apex angle of 90° was cut at a certain height. Therefore, the cut micro-pyramids have a flat area on their top, and the angle of the inclined surface with respect to the substrate was fixed to 45° . The refractive index of micro-pyramids was fixed to 1.55. The luminance distribution at several heights of the cut micro-pyramids is shown in Fig-

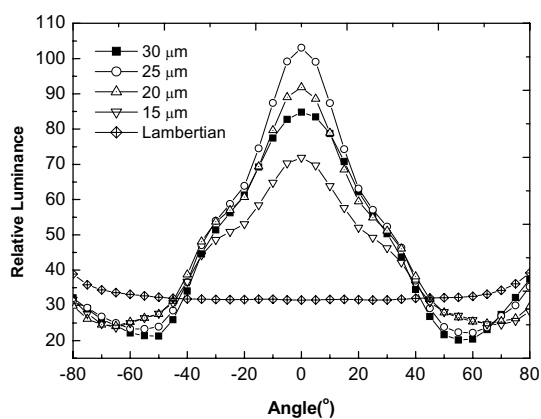


Figure 2. The dependence of the luminance on the viewing angle simulated at several re-shaped micro-pyramids. The numbers denote the height of the cut micro-pyramids.

ure 2. The numbers in the figure denote the height of the cut micro-pyramids. The luminance distribution becomes sharper and the on-axis luminance increases as the height decreases from 30 to 25 μm . The luminance gain becomes a maximum at a height of approximately 25 μm with a minimum viewing angle.

Cut micro-prism sheets

From the above results, similar effects might be expected from the cut micro-prism one-dimensional array. Figures 3 and 4 represent the angular distribution of luminance along directions perpendicular and parallel to the one-dimensional micro-prism array, respectively. The refractive index was fixed to 1.55. The mi-

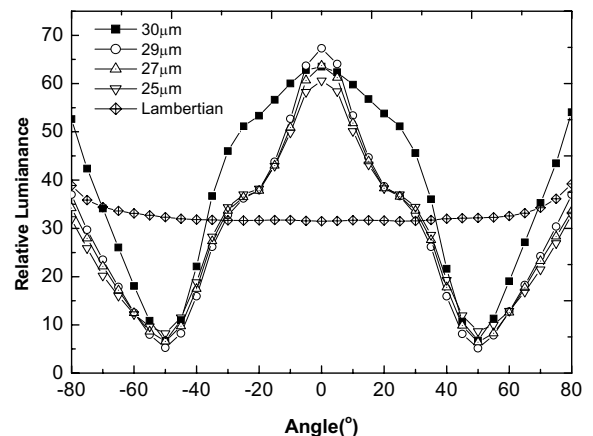


Figure 3. The dependence of the luminance on the viewing angle along the direction perpendicular to the one-dimensional micro-prism array.

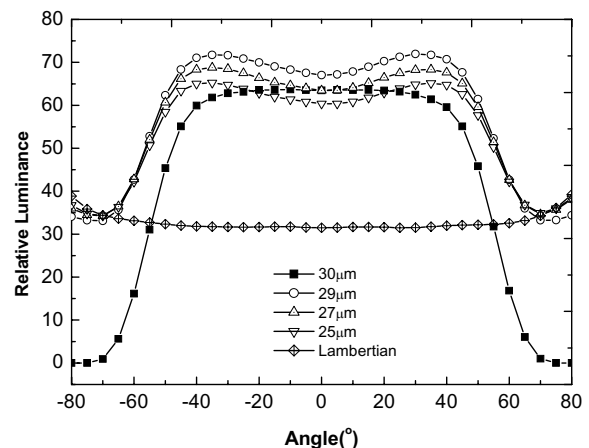


Figure 4. The dependence of the luminance on the viewing angle along the direction parallel to the one-dimensional micro-prism array.

cro-prism array whose height is $30\text{ }\mu\text{m}$ corresponds to the conventional prism sheet. It is interesting to note that the luminance distribution becomes sharper along the perpendicular direction while it is much broader along the parallel direction. In addition, double peak structure in the luminance distribution can be seen in the latter case.

The viewing angle, defined by the half width at half maximum of the luminance distribution, becomes smaller when viewed along perpendicular direction while it becomes much larger along the parallel direction compared to the angular luminance distribution which the conventional prism sheet represents. This is more clearly seen from Figures 5 and 6, which exhibit the luminance gain and the viewing angle estimated from Figures 3 and 4, respectively.

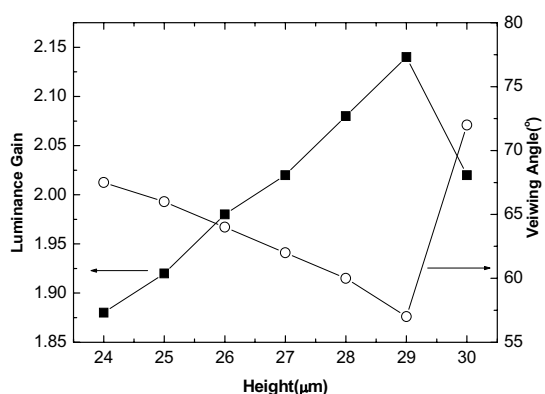


Figure 5. The dependence of the on-axis luminance gain and viewing angle on the height when viewed along the direction perpendicular to the one-dimensional micro-prism array.

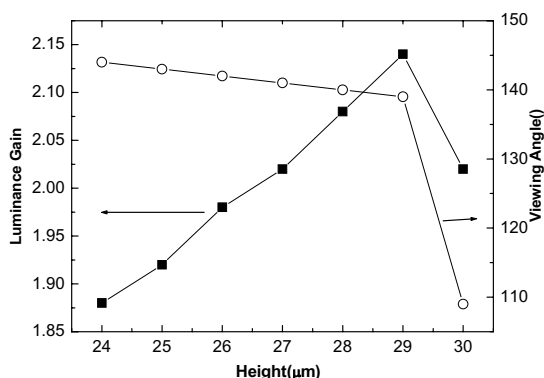


Figure 6. The dependence of the on-axis luminance gain and viewing angle on the height when viewed along the direction parallel to the one-dimensional micro-prism array.

The on-axis luminance gain becomes a maxi-

mum at the height of approximately $29\text{ }\mu\text{m}$. The viewing angle along the perpendicular direction becomes a minimum at the same height while it is much larger than that of the uncut prism sheet when viewed along the parallel direction.

DISCUSSION

The effects of cutting the apex portion of micro-pyramid and micro-prism arrays on their optical performances can be summarized as follows:

1. The angular distribution of luminance becomes sharper than the uncut case in both micro-pyramid and micro-prism arrays. The on-axis luminance becomes larger by removing the apex portion at some heights in both cases than the uncut sheets.

2. In case of cut micro-prism sheets, the angular distribution along one direction becomes much sharper while it is much broader along the other direction compared to that of uncut, conventional prism sheets.

Figures 2 and 3 show that luminance distributions in both cases show a common feature characterized by a sharp central peak overlapped on broad wings. Considering the angular distribution of uncut cases, we can understand that the broad wings are brought about from the refracted rays through the inclined planes while the sharp central peak appears due to the flat surfaces around the apex portion. The rays striking the flat surfaces will be refracted according to the Snell's law towards the on-axis direction because of the small incident angles. Since the rays which are incident on the flat surfaces at almost normal direction will contribute to the on-axis luminance directly, overall luminance gain becomes a little bit larger than the value of the uncut prism sheet. However, if the height of cut micro-prism becomes lower and lower, the recycling efficiency of rays via total internal reflections at inclined surfaces would decrease resulting in lower luminance gain.

On the other hand, the luminance distribution along the direction parallel to the one-dimensional micro-prism array is much broader than the uncut case and shows double peak structure. It means that the luminance at the viewing angle of $\sim 40^\circ$ is even larger than the on-axis luminance. This undesirable effect can be controlled by changing the refractive index of micro-prisms. The rays incident on the flat surfaces on top of micro-prisms would be refracted more towards the on-axis direction upon the increase of refractive index according to the Snell's law. Figure 7 shows the dependence of the angular distribution of the luminance on the refractive index when viewed along the direction parallel to the one-dimensional micro-prism array. As the refractive index increases, the double peak

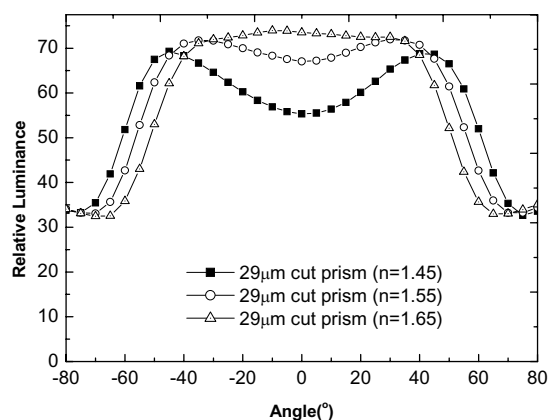


Figure 7. The dependence of the luminance distribution on the refractive index when viewed along the direction parallel to the one-dimensional micro-prism array.

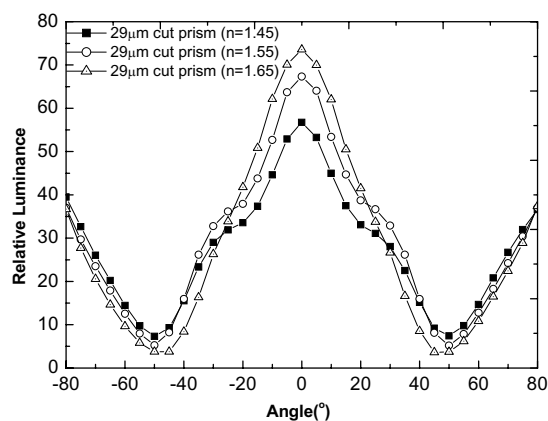


Figure 8. The dependence of the luminance distribution on the refractive index when viewed along the direction perpendicular to the one-dimensional micro-prism array.

structure becomes smeared out and disappears at the refractive index of ~ 1.65 . The luminance distribution along the direction perpendicular to the one-dimensional micro-prism array, which is shown in Figure 8, becomes a sharp single peak instead of a central peak overlapped on broader wings when the refractive index increases to 1.65.

As a result, thanks to the existence of flat surfaces on micro-pyramid or micro-prism arrays, we can have one more degree of freedom in addition to apex angle, refractive index, density, etc., for adjusting the angular distribution of luminance.

CONCLUSION

The present simulation results showed that optical performances of the micro-pyramid and mi-

cro-prism arrays, that is, the angular distribution of the luminance and the on-axis luminance gain can be controlled by adjusting not only the density, the apex angle, the refractive index but also the re-shaping condition of the micro-lenses.

The luminance gain of the micro-pyramid array showed a maximum at the condition of the apex angle of 90° , the refractive index of 1.65 which is the highest value used in the present simulation, the maximum density (no space between micro-pyramids), and the cut height of $25\ \mu\text{m}$. The light-collecting performance represented by the luminance gain of the micro-pyramids under these best conditions was much superior to that of the conventional prism sheet.

In case of cut micro-prism arrays, they exhibited extremely anisotropic angular distributions of luminance, i.e., the angular distribution along one direction becomes much sharper while it is much broader along the other direction compared to that of uncut, conventional prism sheets. This property might be used to control and optimize the viewing-angle characteristics of one-person-use LCD such as PDAs or notebook computers.

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

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