

Light Output Characteristics of Rounded Prism Films in the Backlight Unit for Liquid Crystal Display

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Abstract

The optical performances of rounded prism films were investigated using a ray tracing technique. The angular distribution of the luminous intensity was obtained as functions of the prism pitch and the curvature of rounded apex and valley of prism arrays. The gain of the on-axis luminance decreased with decreasing curvature (increasing diameter) and pitch. The existence of the curved area on the prism film decreased the recycling efficiency of the prism film, i.e., the rays which would otherwise have been recycled through total internal reflections via the prism surfaces were refracted on the curved regions and redirected toward directions other than the on-axis direction. Quantitative correlation between the luminance gain and the curvature in addition to the prism pitch was obtained, which might serve as basic data for the optimization of prism films and the manufacturing processes.

Keywords : backlight unit (BLU), prism film, curvature effect, luminance gain, light collimation (Category: Display Material and Components)

1. Introduction

Display is a device that converts electric signals containing image information into a series of images on a screen. Display can be categorized into either emissive type or non-emissive type depending on whether it generates primary lights by itself or it just controls the transmission and the spectrum of externally-supplied light for producing images. Liquid crystal display (LCD) is a representative non-emissive display because it always needs a white light supplied by an independent part called backlight unit (BLU). The function of BLU is to supply LCD with a bright, uniform, and white light. The orientation of liquid crystals in LCD, which is controlled by thin film transistors (TFT) on the back plate, determines the amount of transmitted light along with two polarizers, while the color filter on the front glass of the panel reshapes the spectrum of the incident white light for the formation of three primary colors. The color temperature and color coordinates of LCD are mainly determined by the spectrum of the white light from the BLU.

BLU consists of many parts such as light sources, a light guide panel (LGP) for edge-lit type BLU, a diffuser plate for direct-lit type BLU, several optical films, mold frames, driving circuits, etc[1,2]. Among them, optical films are used to homogenize the light and/or manipulate the angular distribution of light output of BLU and thus to increase the on-axis luminance[3]. In case of direct-lit BLU, tubular fluorescent lamps such as cold cathode fluorescent lamps (CCFL) are arranged parallel, below which a reflection film is located to redirect the white light generated from CCFLs toward the LCD panel. Above CCFLs, the diffuser plate is put to homogenize the distribution of the output light resulting in the Lambertian distribution on it, which means equal luminance irrespective of the viewing angle. The diffuser sheet on the diffuser plate further homogenizes the light and slightly modifies the angular distribution of the light enhancing the on-axis luminance. The prism film further collimates the light through the refraction of rays on the surfaces of one-dimensional micro prisms and thus enhances the on-axis luminance. The light-collimating power of lens films depends on many parameters such as the refractive index, apex angle or cross-sectional shapes, density of micro-lenses, etc.[4,5]. In addition, a reflective polarizer[6] can be

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used to further increase the on-axis luminance.

Prism films are composed of one-dimensional micro prisms whose pitch is usually a few tens of μm. These micro prisms are usually made from acrylic resin on a PET substrate. The apex angle of each prism is normally 90° for maximum optical gain[7]. However, during the real manufacturing processes, the sharp apex of the prism and/or valley between prisms of the mold may not be copied correctly onto the prism pattern made from acryl resin resulting in rounded shapes. Although prism films are widely adopted in both edge-lit and direct-lit BLUs, the relationship between the microscopic shapes of prisms and optical performances is not clearly revealed. The curvature of the apex of micro prisms can be used to determine the accuracy of the manufacturing process of prism films. The present study is devoted to the investigation of the correlation between the curvature of the apex of micro prisms and optical performances of prism films by using a ray tracing simulation technique. The result will be served as basic data for the design of efficient light collimating films reflecting the effect of rounded aperture and thus optimization of the mass production process.

2. Simulations

The prism film constructed for the simulation consisted of substrate and micro prisms on it. The thickness of the substrate was 125 μm with a refractive index of 1.492. The total are of the substrate was 9 cm^2. The pitch of the prism was changed in the range between 5 and 60 μm, and the refractive index was fixed to 1.6. In order to check the effect of rounding the apex and valley portions on the optical performances, we formed curved regions having a certain diameter in these regions. The diameter of the curved region was set to be 2, 4, and 6 μm. Fig. 1 shows one example of the cross-sections of the modified micro-prisms having curved regions with a diameter of 4 μm on top of the apexes and the valleys between the prisms.

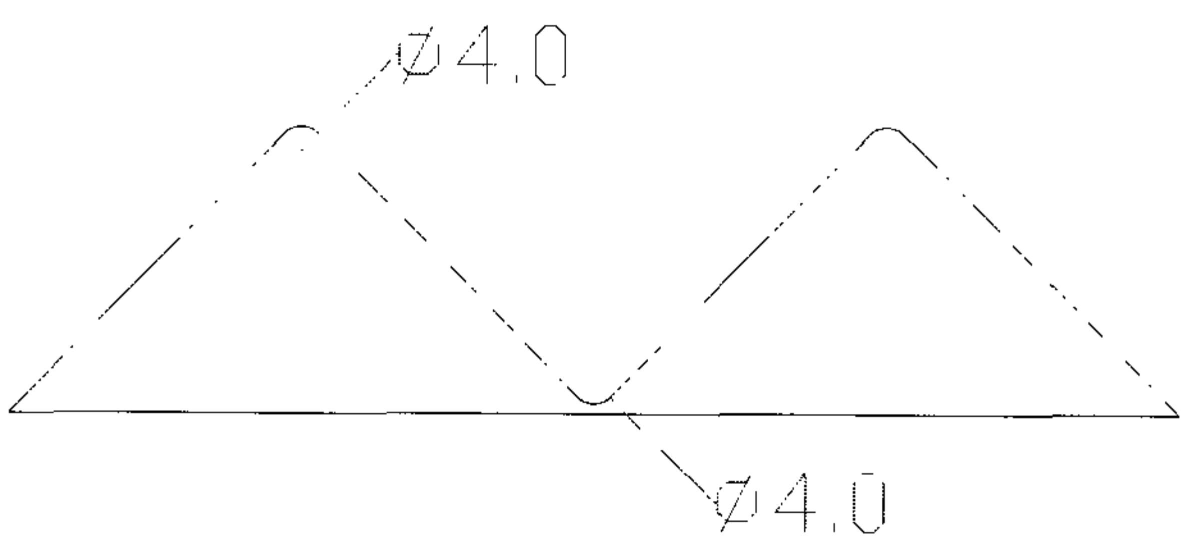


Fig. 1. A cross-section of the modified micro- prisms having curved regions with a diameter of 4 μm at the apexes and valleys.

A ray tracing technique using the ASAP 2005(ver.1) (Breault Research Org.) was adopted for the simulation. Constructed prism films were put on a perfect mirror reflector. Between the reflector and the prism film, a virtual Lambertian light source with the same size was inserted. Above the prism film, a detector was put in order to check the angular distribution of the output light from the prism film.

3. Results

3.1 The effect of pitch on optical performances

As a first step, a conventional prism film was designed with a prism pitch of 60 μm. The angular distribution of the luminous intensity along the directions parallel and perpendicular to the prism direction is plotted in Fig. 2 in

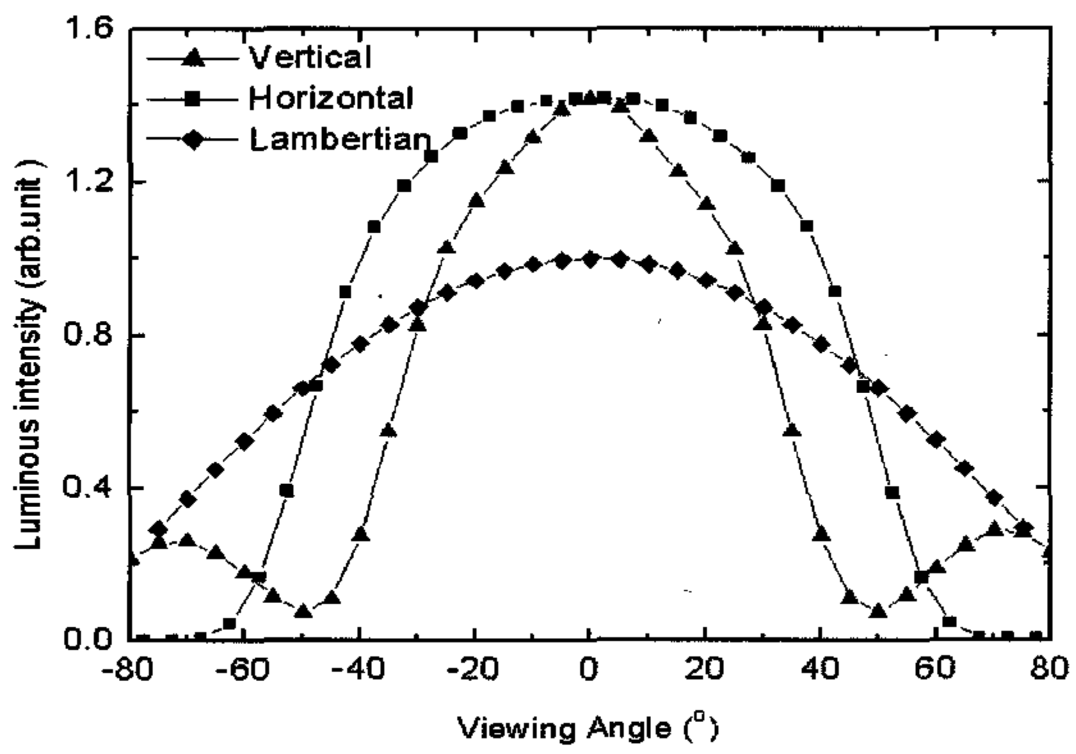


Fig. 2. The angular distribution of the luminous intensity along directions parallel and perpendicular to the direction of the one-dimensionally aligned prisms. The Lambertian distribution was also plotted for comparison.

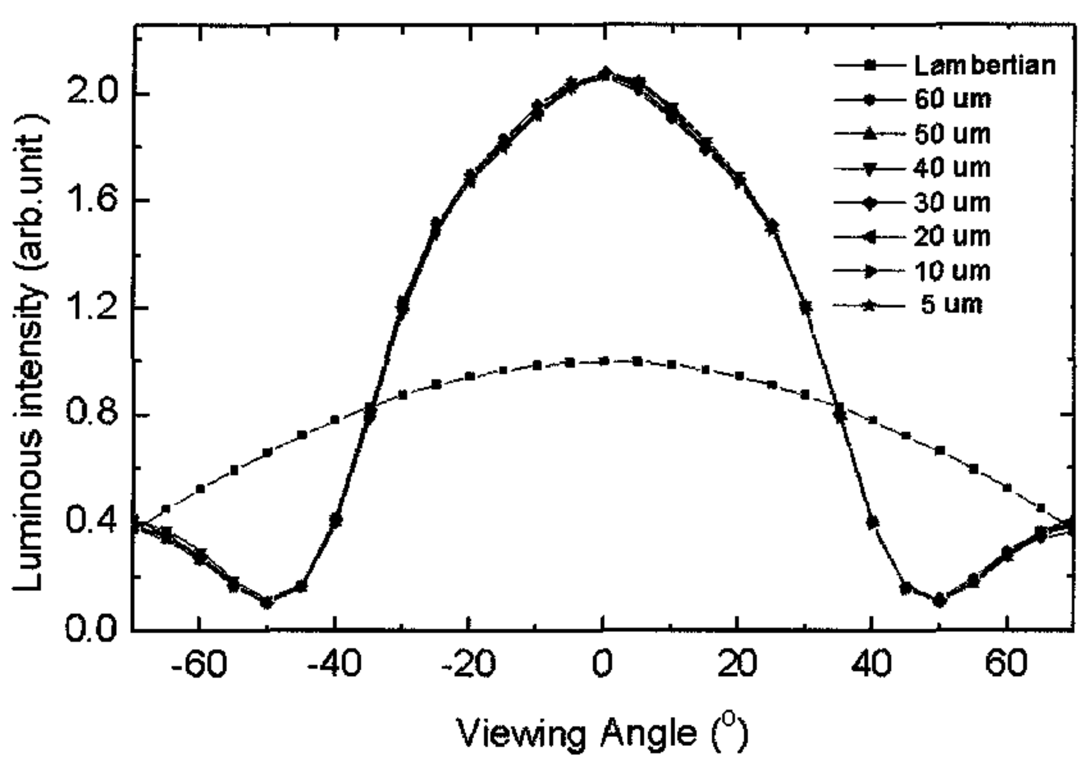
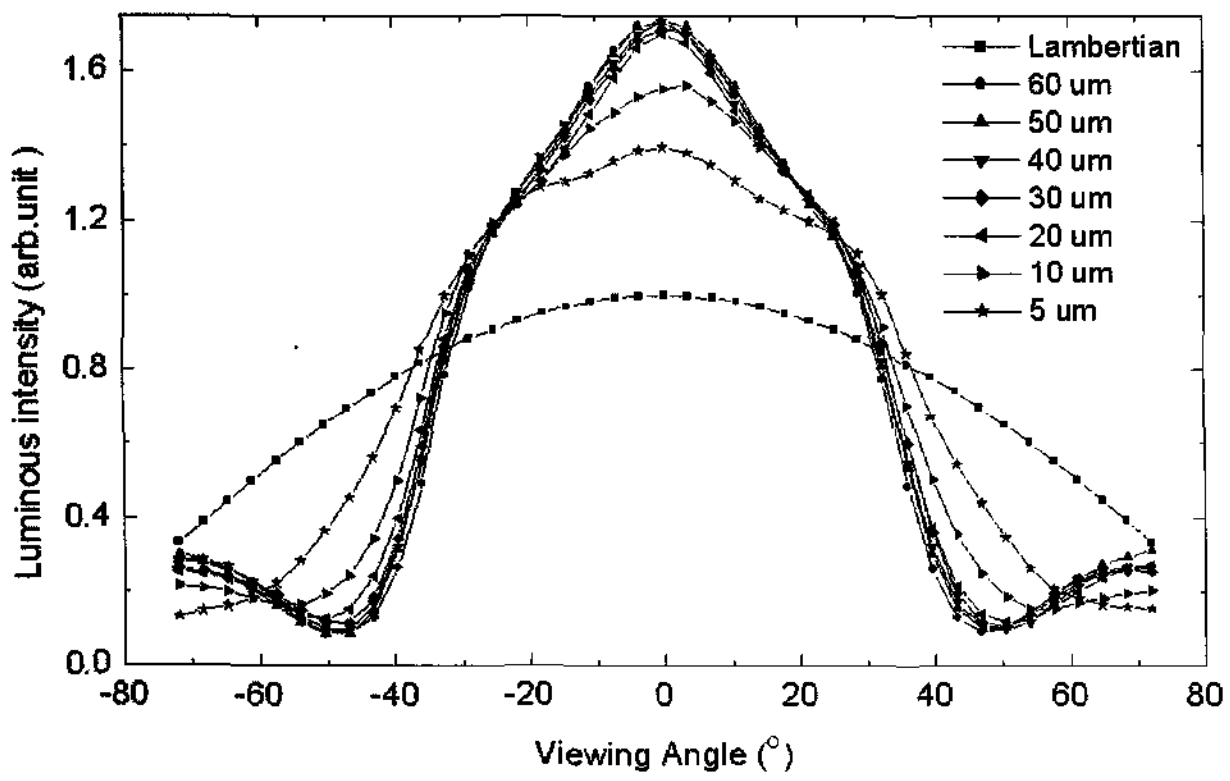
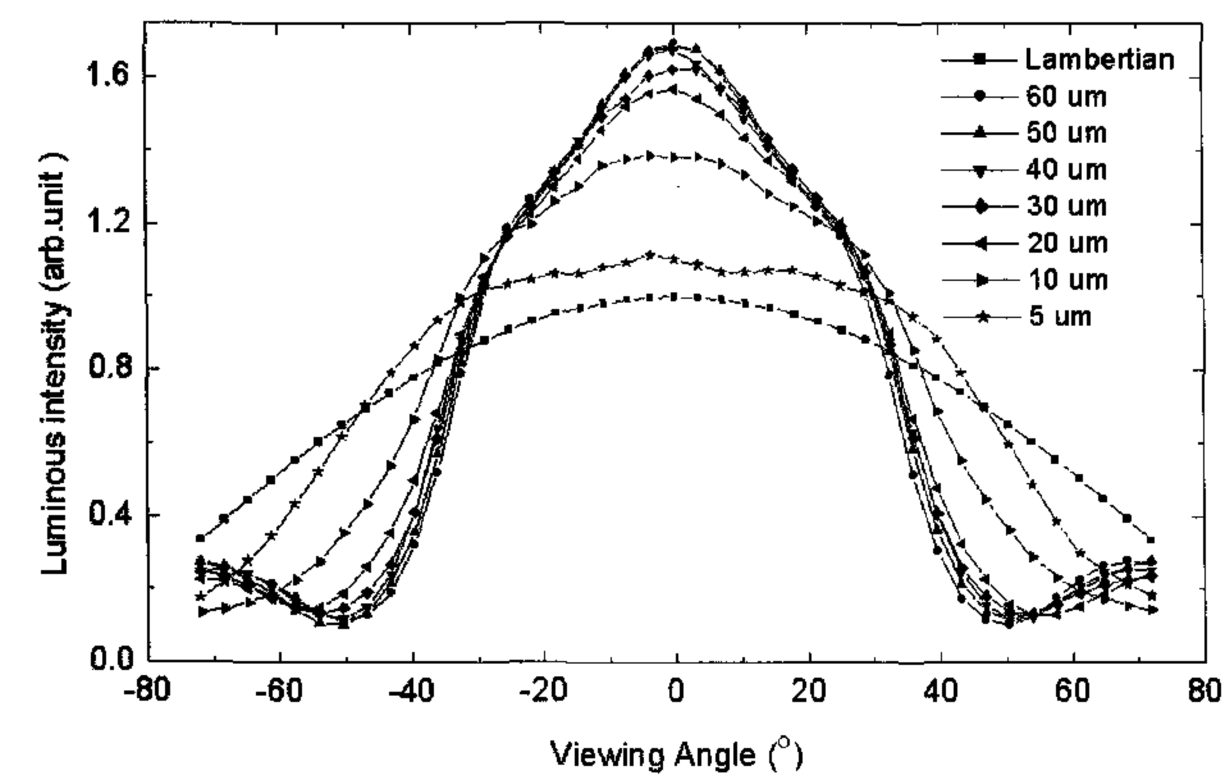


Fig. 3. The angular distribution of the luminous intensity along the perpendicular direction of prism films at various pitches.

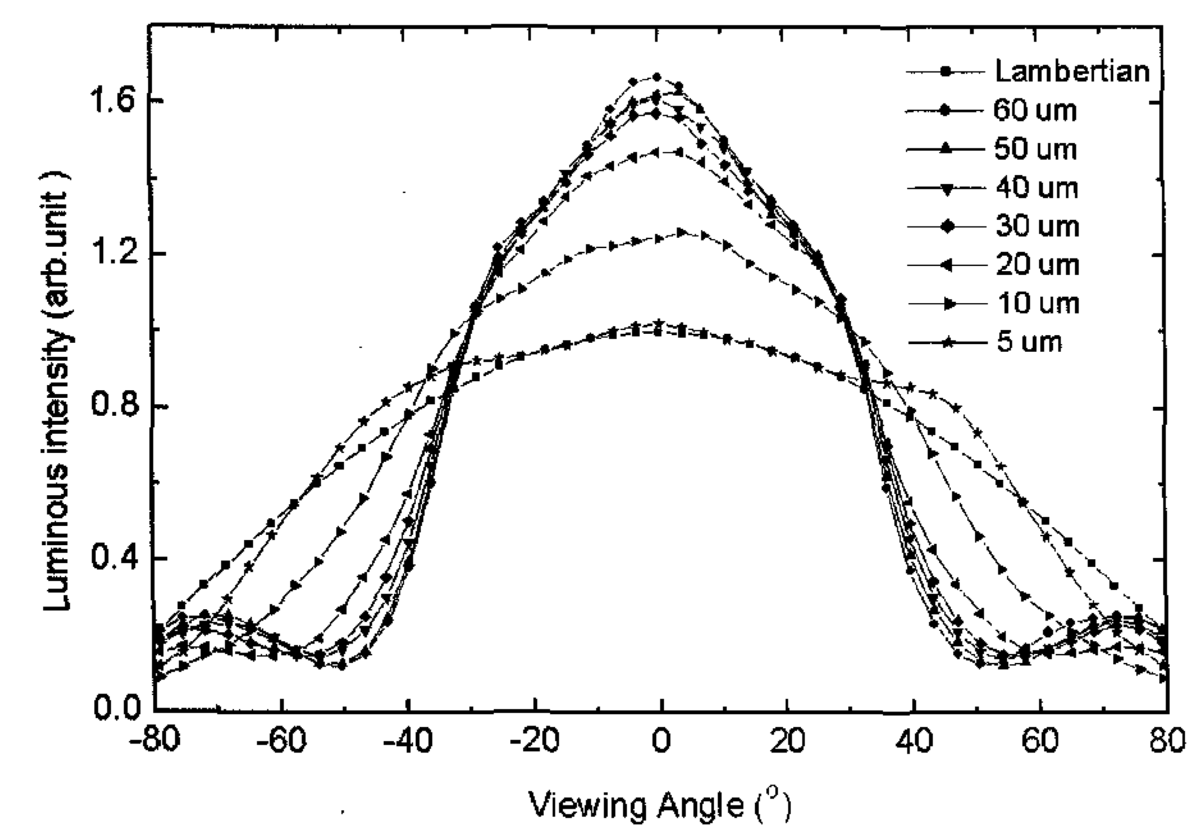
addition to the Lambertian distribution of the virtual light source as a reference. One could discern that the existence of the prism film affects the angular distribution along both directions in different ways. The angular distribution along the perpendicular direction became much sharper owing to the refraction of rays at the prism surfaces towards the on-axis direction. In addition, side lobes resulting from the rays that first experience total internal refection(TIR) and then refracted toward high viewing angles can also be seen. The overall features are very similar to those of conventional prism films, reflecting the accuracy of the present simulation.



(a)



(b)



(c)

Fig. 4. The angular distribution of the luminous intensity along the perpendicular direction at the diameter of curvature of (a) 2, (b) 4, and (c) 6 μm

Next, the pitch of the prism was adjusted in the range between 5 and 60 μm. Fig. 3 shows the angular distributions of the luminous intensity along the perpendicular direction at various pitches. One could not observe any significant differences from differing pitches. The number of prisms in unit area does not affect the optical performances of prism films when the pitch is in the range above 5 μm, which is still much larger than the wavelength of the visible light. However, it should be noted that the optical performances of the real, conventional prism films might depend on the pitch, i.e., the on-axis luminance is known to become larger with increasing pitch in a certain range.

3.2 The effect of curvature on optical performances

The diameter of the curved region at the apex and valley was fixed to be 2, 4, and 6 μm. Figs. 4 (a), (b), and (c) show the angular distribution of the luminous intensity along the perpendicular direction at the diameter of 2, 4, and 6 μm, respectively. If there is a curved region on the surface of micro prisms, the angular distribution of the luminous intensity becomes wider and the on-axis luminance-

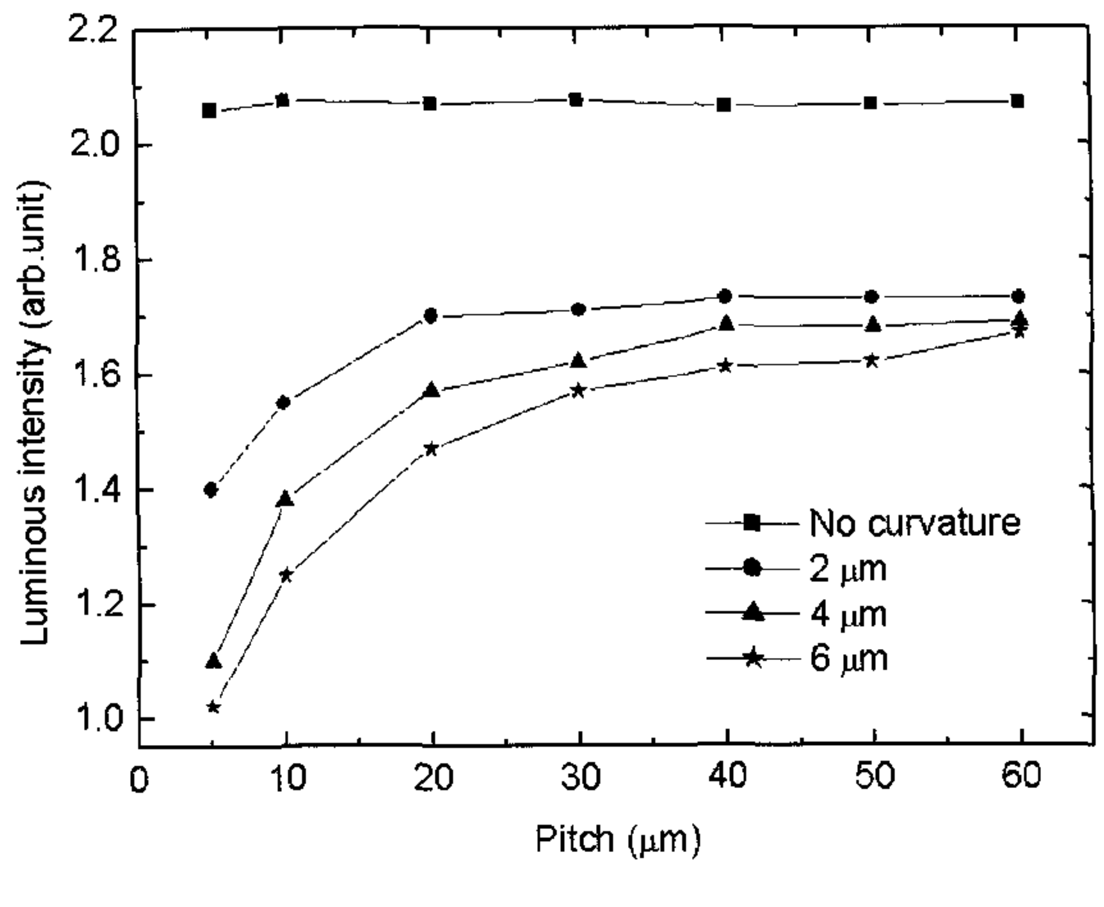


Fig. 5. The on-axis luminance gain with respect to that of the Lambertian distribution, which was set to be 1, at various pitches and at three diameters of the curvature.

decreases with decreasing pitch. If the pitch approaches 5 μm, the distribution becomes much closer to the Lambertian one. In addition, if the diameter becomes larger at the same pitch, the on-axis luminance decreases. Fig. 5 summarizes the on-axis luminance gain with respect to that of the Lambertian distribution at various pitches for the three diameters investigated in the present study. It can be found that the on-axis luminance is sensitive to both the pitch and the diameter(curvature), in particular, when the pitch decreases.

4. Discussion

With respect to the ray division at the prism film, if the Lambertian rays strike the substrate of the prism film whose refractive index is 1.492, they will be confined in the angles from -42 to +42° with respect to the normal direction according to the Snell's law. If these confined rays meet the prism pattern, approximately 37 % of them will be refracted and collimated toward the on-axis direction, contribution to the on-axis luminance gain, while about 46 % will experience TIR twice and then redirected downwards[8]. The remaining rays will either strike neighboring prisms or be directed to directions of high viewing angles, contributing to the build-up of the side lobes in the angular distribution of the luminous intensity. The rays redirected downwards will partly be absorbed by other optical sheets or fluorescent lamps and partly be reflected and reenter the prism film again. These recycled rays are an important part of the high luminance gain of prism films, and it is important to keep the apex angle to be 90° for better recycling effect and thus higher luminance gain[7].

In order to investigate the recycling effect due to the double TIR from prism surfaces, we either modified the apex angle to be other than 90° or changed the flat surfaces of isosceles triangular prisms into curved surfaces. All these modifications resulted in lower gain of on-axis luminance. The results summarized in Fig. 5 confirm the above. As the diameter of the curved regions of apexes and valleys, the portion of rays experiencing TIR's would decrease, and the curved surfaces tend to refract the rays toward directions other than the on-axis direction. If the pitch decreases at the same curvature, the density of curved regions would increase, resulting in the decrease of the recycling efficiency via TIR.

From this context, it is recommended that the prism pitch be kept above approximately 20 μm when there are curved parts on the apex and valley regions whose diameter is in the range 2~6 μm. The present result can be used to correlate the optical performances of manufactured prism film with detailed micro-structure of prisms, in particular, the curvature at the apex and/or valley in addition to the prism pitch.

5. Summary

The optical performances of prism films were investigated as functions of the prism pitch and the curvature of apex and valley regions of micro prisms by using a ray tracing tool. The angular distribution of the luminous intensity became wider and the gain of the on-axis luminance decreased with increasing diameter of the curved regions and decreasing prism pitch. These results could be explaining considering the role of the prism surfaces in recycling the rays via total internal reflection. As we have more curved area on the prism film, the recycling efficiency through TIR would decrease resulting in lower gain of the on-axis luminance. The quantitative relation between the luminance gain and design parameters of prism films, in particular, the curvature of the apex and the prism pitch may serve as basic data for optimizing manufacturing process of prism films. Further studies on the curvature effect on other light collimating films are required and will be reported in succeeding articles.

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