HIGH GAIN LEXAN™ DIFFUSER FILM FOR LCD DISPLAYS

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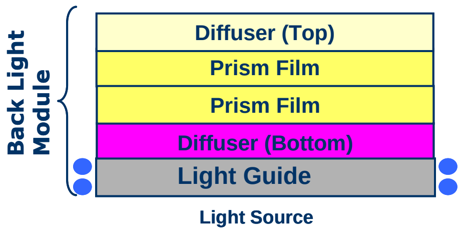
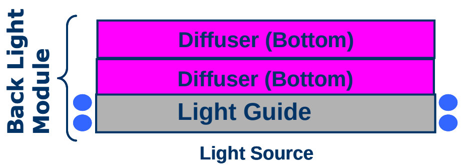
INTRODUCTION

Liquid Crystal Display, commonly referred to as LCD, has become a widespread technology for a variety of display applications. These include flat panel computer monitors, TVs, notebook computers, mobile phones, navigation systems, advertisement boards, and a number of video display consoles in other applications. An LCD Display comprises two primary components for delivering a video image to the viewer: a Back Light Module (BLM), and the Panel. BLM is the light source providing necessary illumination for the system, whereas the Panel is the picture making element which converts the video signal into images. Light from the BLM illuminates the panel so the images are visible to the viewer. Image quality is therefore dependent, in part, on the quality of light generated by the BLM. Common attributes describing image quality that could be linked to the back light include: brightness, viewing angle, image uniformity, and cosmetics (such as point-defects).

A BLM relies on a stack of optical films that gather, redirect, condition, and deliver the source light (CCFLs or LEDs) towards the panel [1]. Attributes of the individual films in the stack dictate the module's ability to meet luminance (brightness) and uniformity requirements of the entire display. Stack design (number, type, and arrangement of films in the stack) varies by lighting configuration (edge-lit or direct-lit), manufacturer, performance, and power consumption requirements. Figure 1(a) shows an example of a typical or standard film stack for an edge-lit BLM where the CCFLs are placed proximate the edges of the light guide.



(a) Standard Film Stack



(b) 2-Film Stack

Figure 1. Stacks for Edge-lit BLM.

The first film in the standard stack, or the "bottom diffuser", has an important function of gathering light and redirecting it towards the next film. This functionality is often referred to as "collimation" since the film steers light travelling in all directions towards a preferred direction. In addition the bottom film diffuses and blends light from different lamps and delivers an even light intensity (or luminance) distribution. This is often referred to as "Hiding Power" of the diffuser; or the ability of a diffuser film to hide the spatial differences in light intensities from an array of lamps. These two, often conflicting, requirements of a bottom diffuser drive innovative optical designs of such films. Additional films in the stack (prism and top diffuser films) further steer and condition the light for illuminating the panel.

In the current work, diffuser films exhibiting excellent light redirecting capabilities while retaining hiding power (diffusion) are discussed. The approach used is to create engineered light turning elements, micro-lenses, directly on the film in the same melt calendering process that is used to make the film. Other approaches used in the industry, Figure 2, include application of bead-filled coatings to produce the collimation effect. More recently, coatings having micro-lens geometries were introduced, Figure 3. Such films have the performance needed in LCD applications; however, they both require additional post processing steps of the optical film (typically bi-axially stretched PET film) to accomplish desired functionality.

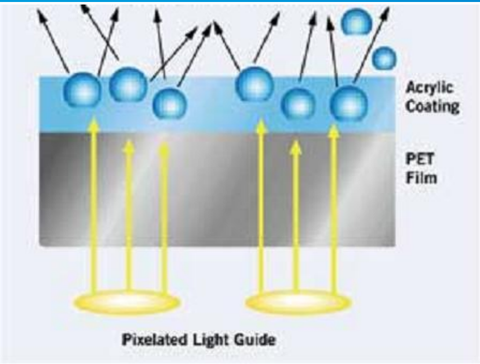


Figure 2. Bead-filled coated diffuser.

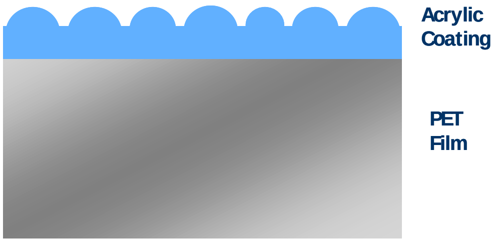


Figure 3. Coated diffuser.

It is worth noting that legacy bottom diffuser (BD) films provided diffusion only, and the BLM relied on the additional light redirecting films (such as prismatic films) to steer the light. Use of light collimating and diffusing films, such as those discussed here, provide additional luminance gain for the module. Moreover, the light collimation characteristic of such films enabled an efficient economic stack comprising only 2 of such films, Figure 1(b), thus reducing the cost of the BLM. Such stacks are attractive from a cost vs. performance standpoint. Their performance is typically in the 80-90% range of a standard stack. Primary focus of the current work will be on BLM comprising 2-Bottom Diffuser stacks. Standard stack performance will be used throughout as a reference point.

OPTICAL DESIGN OF FUNCTIONAL SURFACES

Light rays travelling through and exiting an optical film follow light refraction physics. The slope of the surface elements dictates the exit direction of a light ray. Controlling the manner in which light rays exit a surface is therefore possible through controlling the surface slopes. In another research development [2], the authors identified desirable slope distributions for a surface that are necessary to “turn” light rays in a desirable direction (e.g., towards the viewer).

Simulation Approach

Ray tracing algorithms utilizing Monte Carlo simulations of light rays travelling through the film were employed to perform parametric studies of the effects of surface geometry on the direction and intensity of light exiting the film. Figure 4 shows a schematic of the ray tracing approach used. Light rays incident on the exit surface at an angle larger than the critical angle for film material, will go through Total Internal Reflection (TIR) and will not exit the surface. Such rays, will keep bouncing between surfaces of the film (and reflectors in the back light module) and change their direction until they exit the surface at a desirable exit angle; hence the collimation behavior of the film.

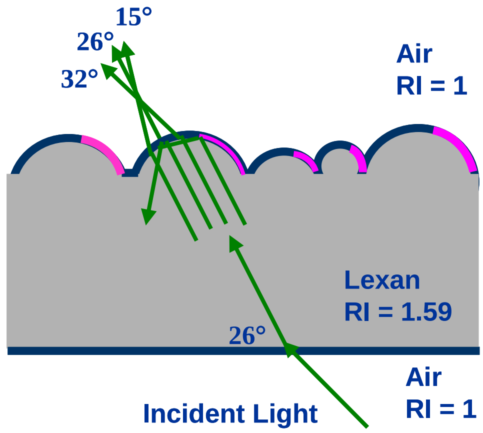


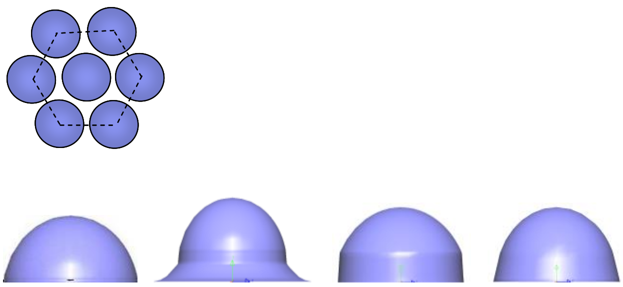
Figure 4. Ray tracing approach.

The same ray tracing approach is used to generate data indicative of an entire BLM's luminance, hiding power, and viewing angle characteristics. This is accomplished by performing area assessments so that the effects of spatial differences in the light source and/or film surfaces, observed from different locations at different angles, are estimated.

Micro-lens Geometry

An optimum bottom diffuser is one that has light turning elements, such as micro-lenses, covering the entire exit side of the film. Hemispherical lenses that are closely packed meet the slope distribution requirement [2] for optimum light redirecting. Close packing of micro-lenses in a hexagonal arrangement, Figure 5, offers an efficient packing scheme. Throughout the current work, hexagonal packing of similar micro-lenses is used, and performance of actual films conforming to such geometries are discussed.

An ideal hexagonal micro-lens pattern is one having zero gaps between lenses that are perfect hemispheres, and perfectly smooth land-areas between the lenses. In contrast, an actual film will have finite gap between the lenses, distortions to the hemispherical geometry, and possibly some roughness in the land area. To understand the impact of departure from an ideal pattern, numerical experiments were run using above ray tracing approach to study the effect gap and lens contour. Descriptors for micro-lens geometry were selected based on observations on actual films. Roughness of land area between cells was not included in the simulation as it is less challenging to obtain smooth surfaces if desired. Figure 5 depicts the different micro-lens contours used in the simulation. Except for an ideal hemispherical geometry (contour a), each contour is divided into three sections: a dome, side-wall, and a flange; each having geometric dimensions and weights that were selected based on observations on actual micro-lens films.



(a) (b) (c) (d)

Figure 5. Micro-lens contours used for simulations.

For simplicity, performance of different film stacks is presented as a ratio of a standard stack. Performance of the standard stack is therefore used as reference (100%). This eliminates design, light source, and model dependencies, and highlights the effect of film geometry selection on performance. The reference (standard) stack used in current work is shown in Figure 1 (a), and comprises a bottom diffuser (of the bead-filled coating type), two prismatic films with prism directions crossing each other, and a simple top diffuser. This is a common edge-lit BLM arrangement used in a variety of LCD displays. Corresponding 2-film stack edge-lit BLM configuration is shown in Figure 1 (b).

Numerical experiments were run to predict luminance in a 2-stack film configuration relative to the standard stack. The four geometries of Figure 5 were used. Gap between the lenses was represented as a ratio of the center-to-center distance. This dimensionless parameter spanned the range 0.0 to 0.23. Zero represents an ideal hexagonal packing of perfect hemispheres with no gaps (contour a), whereas 0.23 represents a case of distorted lenses (contour b) where the flanges in the contour contribute to the large gap. Intermediate values of 0.11 and 0.18 were associated with contours c and d respectively. Simulation results for luminance as a percentage of the standard stack are summarized in Table 1, and presented graphically in Figure 6. As anticipated the predictions are indicating that larger gaps between the micro-lenses and shape distortions are two key factors affecting luminance level. The predictions further provide the sensitivity of luminance to such factors, and are invaluable for setting practical targets when making actual film. The approach was useful in streamlining experimental work in a cost effective manner. In the following sections making of micro-lens diffuser film is briefly discussed, and actual performance data are presented.

Table 1. Ray tracing luminance predictions.

Contour	Gap/ Center-to-Center Distance	Luminance (% of Standard Stack)
a	0.00	92.0%
b	0.23	78.0%
c	0.11	85.0%
	0.18	82.1%
d	0.11	86.8%
	0.18	85.0%

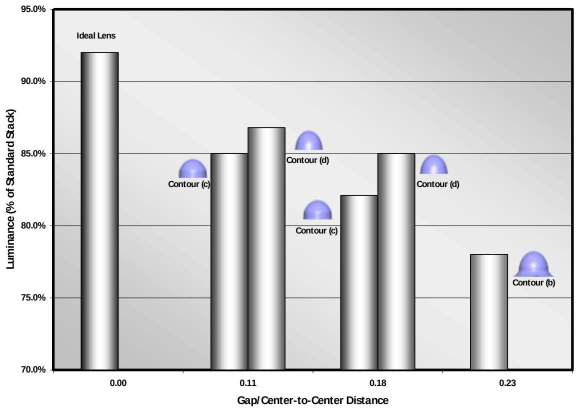


Figure 6. Relative luminance (predicted) change with lens geometry and packing.

LEXAN™ MICRO-LENS FILMS

LEXAN™ micro-lens films (75-450 µm) are made in a melt calendering process, where the molten polycarbonate resin is quenched into film as it passes through the nip of two chill rolls [3]. A negative image of the desired pattern is created on one of the chill rolls [4], the mastering tool. During calendering, the pattern is replicated to the film under nip forces between the two rolls. Replication to the film occurs at a certain efficiency that is dependent on line design, nip forces, heat management in the calendering stack, and flow characteristics of the polymer. Different calendering lines have different replication behaviors; those need to be fully characterized and suitable process window identified, in order to be able replicate and control engineered surface features such as the micro-lenses discussed here.

For the current work mastering tools having lens designs similar to those of contours b, c, and d were made and used to make actual film material. Micro-lens sizes of 10-100 µm were made. The resulting film surfaces are shown in Figure 7 for contour b, and Figure 8 for contours c or d (the two contours look very similar under the microscope). The film of Figure 7 is often referred to as Basic Lens (BL) diffuser film, where as those of Figure 8 are referred to as “High Gain” diffusers.

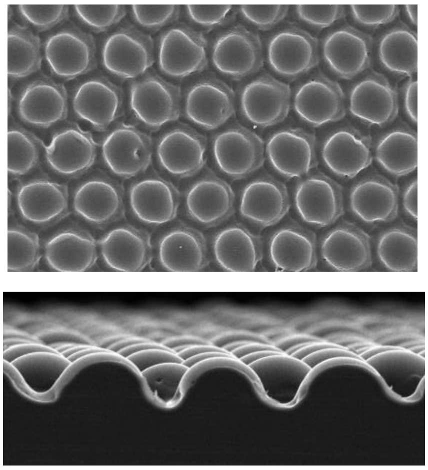


Figure 7. SEM of Basic Lens Diffuser Film.

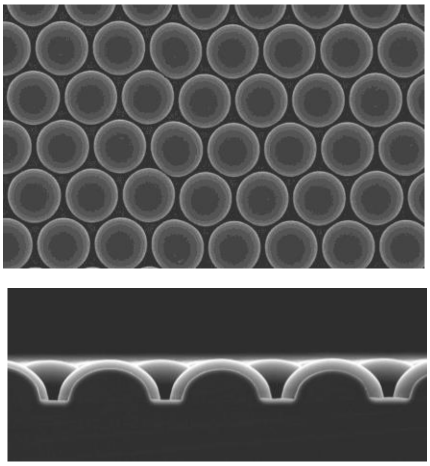


Figure 8. SEM of High-Gain Diffuser Film.

The three films were tested in actual BLMs and luminance measurements were performed in 2-stack configuration. Resulting performance relative to an actual standard stack is depicted in Figure 9. Performance of two reference coated diffusers is also shown. These were A: Bead-filled coated PET film (Figure 2), and B: Coated PET diffuser (Figure 3).

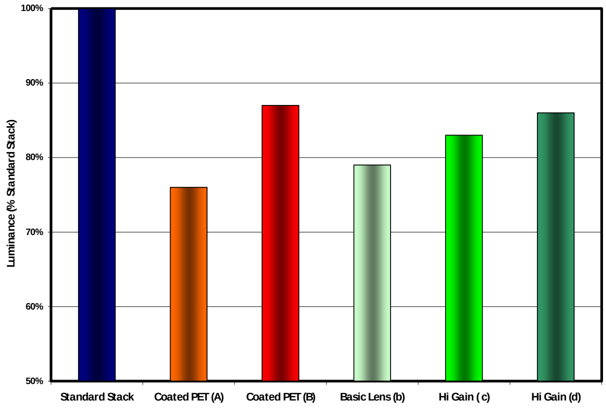


Figure 9. Measured relative luminance

Measured luminance values for the Basic Lens, High Gain, and coated PET diffusers are summarized in Table 2. Where applicable, predicted values are also included.

Table 2. Measured/Predicted Luminance Comparison

	Measured Luminance	Predicted Luminance
Standard Stack	100%	100%
Basic Lens (b)	79%	78%
Hi Gain (c)	83%	82%
Hi Gain (d)	86%	87%
Coated PET (A)	76%	--
Coated PET (B)	87%	--

DISCUSSION

Measured luminance for the Basic Lens diffuser in a 2-film stack exceeded that of a commonly used bead-filled coating on a PET film (A); 79% vs. 76%. The difference may relate to the maturity of the micro-lenses on the surface of the bead-filled coating. As such diffusers rely on the beads erupting from the coating surface to form micro-lenses and provide the optical functionality; it is foreseeable that some of the beads are not sufficiently erupted thus forming less efficient lenses. To the contrary, on a Basic Lens diffuser, all micro-lenses mature and fully formed. Performance of the Basic Lens is still lower than that of the coated PET diffuser (B); 79% vs. 87%. In the latter, the micro-lenses are created in the coating in a micro-replication process that is capable of creating mature and controlled micro-lenses. Other than cost and processing disadvantages, these coated diffusers have the desired performance. Luminance level of the Basic Lens diffuser may be explained by the shape distortions and spacing between the lenses. Modeling results indicated that luminance will be negatively impacted when the shape departs from a hemisphere, and when the spacing between the micro-lenses increases. These characteristics are however beneficial in providing an added degree of diffusion and are advantageous in applications requiring higher degrees of hiding power.

High Gain diffusers are suited for applications requiring maximum luminance. Control of the cell contour and packing density was assessed numerically, and implanted in the film making operation. Luminance increased from 79% (for Basic Lens) to 83% and 86% for films (c) and (d) respectively. High Gain diffuser (d) is equivalent in performance to coated PET (B), and is 10 percentage points better than bead-filled coated PET diffusers (A).

It is worth noting that luminance predictions were in good agreement with measured values, Table 2. This observation provided confidence in the simulation approach, and validated the simulation tool for further design changes and additional parametric studies. Identification of geometric attributes of a diffuser film surface for desired functionality is thus possible. However, working back these attributes to a mastering tool and a calendering process window to impart desired surface on a LEXAN™ film can be challenging. Often, a number of tooling iterations and thorough characterization of the calendering process are required before realizing target geometry.

The work discussed here used a 2-stack edge-lit configuration as an example to demonstrate the performance of LEXAN™ micro-lensed diffusers. Similar trends are observed when other designs or stacks are considered. For example, the relative performance in a 2-stack "direct-lit" configuration was found identical to the trend observed in the current work.

CONCLUSIONS

Optical performance of PC micro-lens diffusers in Back Light Modules of LCD display applications is shown to be 10% better than bead-filled coated PET diffuser, and equivalent to coated micro-lens PET diffuser. Effects of lens geometry and packing on luminance were identified, and improvements of 4% and 7% over a Basic Lens design were realized. Light ray tracing simulation tool was developed, validated, and used to streamline experimental work.

References

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2. A.F. Bastawros, et. al, "Light Collimating and Diffusing Film and System for Making the Film", US Patent No. 7,280,277, October 2007.
3. A.F. Bastawros, et. al, "Light Collimating and Diffusing Film and System for Making the Film" ,US Patent No. 7,889,427, February 2011.

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