21

Lens Films and Reflective Polarization Films

F. Hanzawa

Sumitomo 3M

21.1 Introduction

The technologies of lens films and reflective polarization films will be explained in this chapter. These films enhance the brightness and reduce the power consumption of backlight units for direct-view LCDs.^[1,2]

21.2 Fundamentals of Reflection and Refraction

Light traveling from a medium with a high refractive index to a low refractive index experiences total reflection when the incident angle exceeds the critical angle. The case of 100% reflection is called total internal reflection (TIR), in which case the light is confined within the medium having the higher refractive index. This phenomenon is used in optical transmission fibers and light-guide plates in LCD backlight units.

Figure 21.1 shows reflectance as a function of the incidence angle when light travels from acrylate (with $n = 1.49$) into air ($n = 1.0$). Here, R_p and R_s

Figure 21.1 Reflectance of p-polarized and s-polarized light, R_p and R_s , travelling from acrylate ($n = 1.49$) into air ($n = 1.0$).

Figure 21.2 Recycling of wasted light by the use of a BEF.

are, respectively, the refractive indices of the p-polarized light (in the plane) and the s-polarized light (at right angles to the p-polarization). The lens films are designed based on Fresnel's law and fabricated using a resin with high transparency and high refractive index. Percentages of interfacial reflection and refraction are illustrated in Figure 21.2. The useless component of the flux is recycled and changed to 'useful flux' in the backlight/prism and returns to the LCD, enhancing its brightness.

21.3 Lens Films (Upward Direction)

21.3.1 Lens Films (BEFs)

As one of the typical examples of a lens film, the brightness enhancement film (BEF) of Sumitomo 3M will be described. A prism pattern is formed with optical precision on a polyester film having a high optical transparency. The film is attached to the front surface of a backlight unit and is capable of enhancing the brightness by recycling light which is normally wasted. The recycling is achieved by the above-mentioned relations with regard to the difference in refractive index and incidence angle. Figure 21.3 shows the luminance gain with respect to the observation angle. In the diagram, 'BEF II 90/50(V)/BEF II 90/50(H)' denotes that two orthogonally arranged films are stacked, resulting in a luminance gain of 2.2. The lens films play a role in converging the light into the normal direction to the plane of the backlight unit. Usually the BEF is placed on top of a stack of films which consists of a light-guide plate, a reflection sheet and a diffusion sheet. The surface of the lens is facing towards the LCD (upward direction). There is also the case in which the lens surface is facing towards the backlight unit (downward direction) as will be mentioned later.

21.3.2 Lens Films with Round-tipped Lenses (RBEF)

The lens shown in Figure 21.2 has a sharp tip. The round brightness enhancement film (RBEF), on the other hand, has a lens whose tips are round which makes the variation of the luminance gain with respect to the observation

Figure 21.3 Luminance gain versus the observation angle for a BEF II.

angle less steep. Thus the RBEF gives a compromise between high luminance gain and a wide viewing angle.

21.3.3 Random Pattern Lens Films

In order to eliminate optical interference between the lens system and the pixel arrangement of an LCD, BEFs are fabricated whose lenses are arrayed in a non-linear fashion.

21.3.4 Waved Films

The waved films increase the viewing angle while enhancing the luminance. The cross section of the film has a wavy profile instead of a sharp edge. The film is a single polycarbonate plate which is scratch free, so that a protecting film is not required.

21.3.5 Upward Direction Lens Films

Various lens films which enhance brightness and increase the viewing angles are summarized in Figures 21.4 and 21.5. Also nonuniformity of the light

Figure 21.4 Various optical lens films.

Figure 21.5 Luminance gain versus the viewing angle.

Figure 21.6 Images of CCFL lamps appearing on an LCD screen.

output is eliminated by recycling the light proceeding towards the backlight unit. Figure 21.6 demonstrates how the images of the fluorescent lamps appearing on the screen are reduced by using the lens films.

21.4 Lens Films (Downward Direction)

Lens films, whose lens is facing downward, have the capability of enhancing the brightness in the front direction, but with a reduction in viewing angle. The films are mostly used in the side-light type. A careful design is needed for an adequate combination of lens films and the light-guide plate, since the dependence of the luminance on the direction is strong. Recently, an advanced BEF having asymmetric lenses was proposed^[3] for which an even

stronger directivity was obtained. In some mobile phones and PDAs with an LED light source, prisms are arrayed in an arc determined by the distance from the light source.^[4]

21.5 Reflective Polarization Films

21.5.1 Functions

Although the p-polarized light is transmitted through the LCD rear polarizer into the LCD, the s-polarized light is absorbed. The loss can be recovered by inserting a film between the backlight unit and the rear polarizer and converting the s-polarization into p-polarization. The principle of recycling the light is illustrated in Figure 21.7. When a DBEF is not used (normal BL), the entrance polarizer transmits the p-polarized light but s-polarized light is absorbed. On the other hand, with a DBEF, s-polarized light is reflected back to the backlight unit without being absorbed and depolarized by the diffusion and scattering. The new p-polarized component is transmitted to the LCD but the s-polarized light is reflected again to the backlight. The film has the advantage that no reduction of the viewing angle occurs.

A dual brightness enhancement film (DBEF) exhibits a luminance enhancement of 60%. By combining it with a lens film, further enhancement can be

Figure 21.7 Utilization of light with and without a DBEF.

obtained. The BEF and DBEF are applicable to all LCD monitors, car navigation systems, PDAs, digital cameras and so on. Also the luminance enhancement results in a reduction of the power consumption and a lengthening of the battery life for portable instruments.

21.5.2 Structure of a Reflective Polarization Film

Reflective polarization films are formed by stacking resins which are optically anisotropic. The thickness of each layer is controlled to an accuracy of the wavelength of light. The structure of the DBEF and the reflection spectra for x and y directions are shown in Figure 21.8.

21.5.3 Example of Applications

DBEFs tend to become thermally deformed because of the inherent nature of the resins used. To overcome this deficiency, DBEFs are fabricated by laminating them with absorbing polarizers or polycarbonate light diffusion films.

21.6 Resin-type Specular Reflection Films

If the optical anisotropy is removed from the above mentioned reflective polarizer film, then it becomes a mirror film in the visible range. This makes it possible to produce a mirror with only a resin sheet. A dual enhanced specular reflector–metal sheet (DESR–M), a reflector for fluorescent lamps, is made by gluing the resin on a metal film.

Figure 21.8 Film structure and reflection spectrum of a DBEF.

Figure 21.9 Structure of a thin BEF.

21.7 Applications of Films

21.7.1 PDAs

In order to reduce the power consumption, lens films are adopted in most cell phones and PDAs. As shown in Figure 21.9, the base film is thin and the pitch of the prism is small to reduce the total thickness. A matte finish may be used on the rear surface to eliminate the appearance of a moiré pattern arising from optical interference between the LCD pixels and the prism.

21.7.2 Notebooks

The downward-directed films^[4] are frequently used for notebooks because of their luminance and thickness requirements. Upward-directed films, which do not need matching with the light-guide plate, are also employed.

21.7.3 Monitors and TVs

Considering the ease with which large-sized films can be handled, as well as their durability against heat and humidity, relatively thick lens films are used for monitors and TVs. Large-sized TVs often use the RBEF to ensure a wide viewing angle. Figure 21.10 shows thick lens films with 250 μm thick polyester films. For reflective polarization films, polycarbonate diffuser sheets are laminated on DBEF, as shown in Figure 21.11.

Figure 21.10 Thick lens films for large-sized LC-TVs.

Figure 21.11 Thick reflective polarization films for large-sized LCD-TVs.

Figure 21.12 Structure of a brightness enhancement film-reflective polarizer (BEF-RP).

21.7.4 Combination Films

The use of combination films reduces the number of components and also the production cost. Figure 21.12 illustrates an example of a brightness enhancement film–reflective polarizer (BEF–RP) which is made by combining a thin BEF and a DBEF.^[2]

21.8 Standards

21.8.1 TCO '99-03 for FPD Monitors⁽⁵⁾

The TCO '99-03 recommendation for FPD monitors was documented by TCO Development (The Swedish Confederation of Professional Employees). The recommendation limits the vertical and horizontal viewing angles.

21.8.2 TCO '05 for Notebook PCs⁽⁵⁾

Also recommended by TCO Development is a limitation of the half-luminance angle for vertical and horizontal directions. Attention should be paid when using a lens film that reduces the viewing angle by collimating and orienting the light to the front direction.

21.8.3 Environmental Concerns

Environmental concerns have to be considered with the increase in the number of TV sets which are used worldwide. After the Kyoto protocol came into effect on February 16, 2005, CO₂ emissions had to be reduced. Also RoHS, enacted as of July 1, 2006, restricts the use of mercury. Figure 21.13

Figure 21.13 A break down of energy consumption of household appliances.

shows percentage of the total energy consumptions of various home appliances. Air conditioners, refrigerators and general lighting are the worst three appliances. Also the energy consumption of LC-TVs is increasing. It is possible to reduce the energy consumption of LC-TVs by adopting a reflective polarization film. This, at the same time, reduces the number of fluorescent lamps used, and hence there is a reduction in the mercury used.

References

- [1] Maeda, K. (2003) 'Integration and hybridization of the luminance enhancement films', *FPD International Seminar*, E-3.
- [2] Nakahisa, Y. (2003) 'Luminance enhancement films', *The 85th Spring Meeting, Japan Chemical Society* (in Japanese).
- [3] Okada, H. (2004) 'Trends in the R & D of lens films for LCD backlights', *Display Monthly*, No. 4, pp. 14–21.
- [4] Makuta, I. (2004) 'Characteristics of backlight, fabrication process, periphery structures', *Gijutsu Joho Kyokai Seminar*.
- [5] <http://www.tcodevelopment.com/>