

LCD Backlights

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discussed considering the latest technical trends in their constituent parts such as light guides and diffuser sheets.

6.2 Basic Structure and Principles of LED Backlights

6.2.1 Structure of a Backlight with Two Prism Sheets

Figure 6.1 shows the basic structure of the most common type of LED backlight, which incorporates two prism sheets. The basic constituent parts of the LED backlight are the LED module light source, a light guide, a reflector sheet, a diffuser sheet and two prism sheets. The brightness of the LED backlight largely depends on the light-emitting efficiency of the LED module. Back in 2000 when color displays first appeared, the light-emitting efficiency of LED backlights was about 10lm/W. However, their efficiency has been increasing every year and it is currently about 70lm/W. By 2010, it may be possible to achieve 100lm/W, which is about twice the luminous efficiency of the cold-cathode fluorescent devices. Together with the latest RoHS directives which impose broader restrictions on the use of mercury, and the

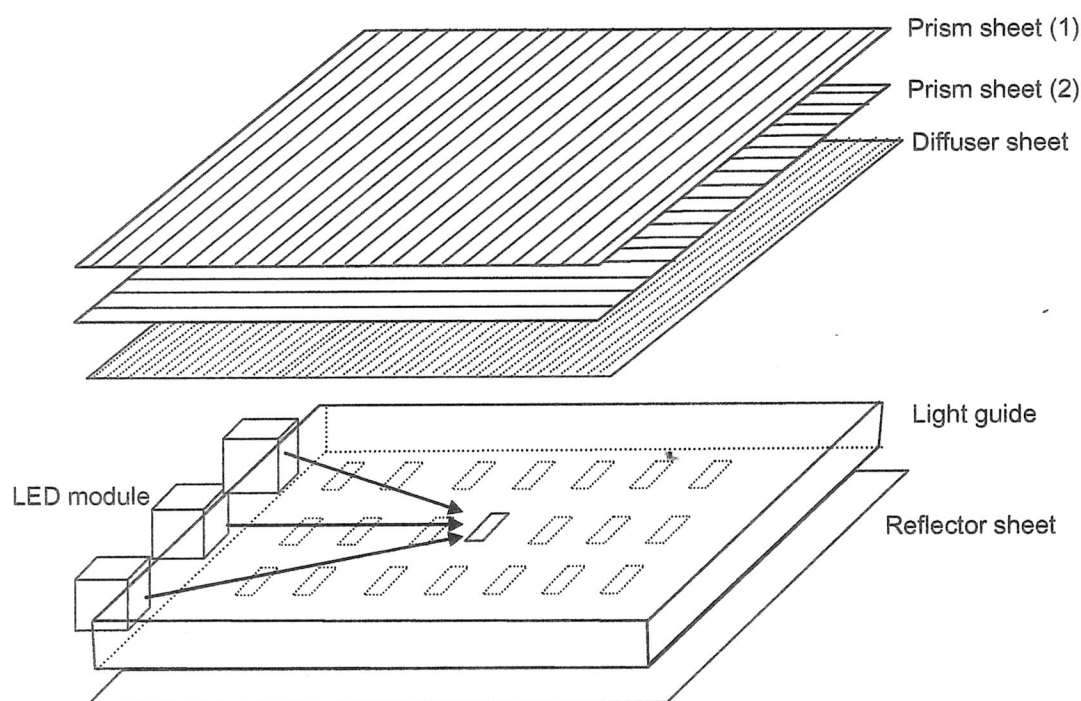


Figure 6.1 Basic structure of an LED backlight unit.

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continuing industrial trend towards energy-saving technology, LEDs are likely to be used increasingly in medium-size backlights for PDAs and car navigation systems.

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The light guide serves to spread the light of the point sources of the LED modules across the plane of the backlight. An arrangement of diffuser dots and/or prisms is formed on the back surface of the light guide so as to achieve an efficient and uniform radiation of light from the light-guide surface. Recent advances in micromachining technology have made it possible to achieve greater details with higher precision, resulting in substantial improvements in emission efficiency and uniformity. The thickness of the light guide was about 0.7 mm for the initial color devices, but with modern technology this has been reduced to 0.4 mm in the latest products. Most of the light guides are made from materials such as acrylate and polycarbonate resins which have superior optical and mechanical properties, but cycloolefin polymer resins are also used in cases where low weight is required. The prism sheets are still essential parts of the LED backlight unit which perform multiple functions of extracting light from the light guide and condensing it into a suitable angular range, while returning the components of light at other angles to the light guide to increase its uniformity, and reducing visibility of defects in the light guide. A backlight normally uses two prism sheets in which the prisms are arranged at right angles. Compared with a single prism sheet, the use of two prism sheets results in a better condensing performance, better luminance uniformity and reduced defect visibility.

The reflector sheet is made of a silver foil formed on a sheet, or of a white sheet of PET. The diffuser sheet can be adjusted to a required level of diffusion by selecting a suitable degree of haze. The properties of the reflector sheet and diffuser sheet – such as their reflectivity, reflection characteristics and diffusion characteristics – are selected to ensure that the radiated intensity and uniformity of light emitted from the prism sheet satisfy the desired properties in combination with the light emission characteristics of the light guide.

There are two ways to increase the brightness of the backlight unit based on the construction of Figure 6.1. One is to increase the coupling efficiency of the materials through which the light propagates from the LED module so that it can be radiated from the prism sheet without loss, and the other is to constrict the intensity distribution of the light emitted from the prism sheets so that a higher intensity is radiated in the direction normal to the plane of the backlight. However, since the structure of the prism sheet is designed to maximize the radiated intensity, there is generally little freedom in the design. As a result, we are restricted to making more efficient use of

the light emitted from the LEDs by increasing the coupling efficiency of the materials. With current technology, it is possible to achieve a coupling efficiency of 95% between the LED module and light guide, a confinement efficiency of 95% in the light guide (whose efficiency increases by reducing the leakage of light from the end surfaces of the light guide) and an efficiency of about 85% in the reflector sheet. As a result, about 75% of the light from the LED module is emitted from the prism sheet. This indicates that even in an ideal case it is only possible to achieve a brightness increase of 25%.

On the other hand, thinner backlights are implemented by reducing the thicknesses of the light guide and other constituent sheets. Approximate thicknesses of the reflector sheet, diffuser sheet and prism sheets were 80 μm , 60 μm and 60 μm , respectively. These have been reduced to about a half due to the above-mentioned trend towards reduced light-guide thickness. Considering the pattern-forming properties and mechanical strength of the light guide and prism sheets, a major breakthrough is needed to achieve further reductions of thickness.

6.2.2 Principles of LED Backlights

An LED backlight unit has three functions: (1) converting the light flux from one or more LED point sources into a planar light source, (2) emitting the light flux from the upper surface of the light guide, and (3) condensing the emitted light with the required level of directivity. These functions are further explained below.

Figure 6.2 illustrates the behavior of a link of an LED module light source with the light guide. The LED module is directly abutted against the edge surface of the light guide. The light radiated from the module is generally assumed to have a Lambertian intensity distribution. Consider the behavior of light rays in the y - z plane of Figure 6.2(a). Of the light rays emitted from the LED module, the rays parallel with the end surface of the light guide (traveling along the z -axis) are refracted at an angle α that satisfies the relationship $n_w \sin(\alpha) = 1$, where n_w is the refractive index of the light guide. These rays are incident on the upper surface of the light guide at an angle $\beta = \pi/2 - \alpha$. To avoid light radiated from the LED module being directly emitted from the upper or lower surfaces of the light guide, it is necessary to satisfy the relationship $n_w \sin(\beta) > 1$. A light guide that satisfies this condition must have a refractive index in the range $n_w > 1.4$.

Next, consider the behavior of light rays in the x - y plane of Figure 6.2(b). Here, it is necessary to minimize the so-called 'eyeball effect' of intensity



Figure 6.2
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Figure 6.2 the light guide hand edge.

19.5.2 Operating Principle and Structure of an Edge-light Type of Backlight Unit

19.5.2.1 Lamps

There are two kinds of lamp: cold cathode fluorescent lamps (CCFLs) and hot cathode fluorescent lamps (HCFLs). Of these, only CCFLs are used for edge light backlights due to their long life, low power consumption, low heat dissipation and thin tubes. In parallel with this, backlights using LEDs are being actively investigated.

19.5.2.2 Light-guide Plates

The operating principle of the edge-light type backlight unit is as follows. Light emitted from a CCFL enters a light-guide plate from the front edge. The light is propagated along the light guide by total internal reflection. When the light hits a dot pattern formed on the back side of the light-guide plate, part of the light emerges from the light-guide plate provided that the incident angle is smaller than the critical angle of 42.2° . The dot pattern has to be designed so as to give a uniform illumination from the plate.

Figures 19.5 and 19.6 illustrate the operating principle of the edge-light unit and an example of the unit structure, respectively. Figure 19.7 shows a photo of a 17-inch monitor. There are several types of light-guide plates: (1) a dot pattern is formed with white ink on one side of the cast mold plate; (2) a textured pattern is formed using an injection molding process; (3) an edge pattern is formed using an injection molding process.

19.5.2.3 Diffusion Film

A diffusion film looks like frosted glass. It is fabricated by dispersing light-scattering particles into a film or by coating diffusion particles onto the film.

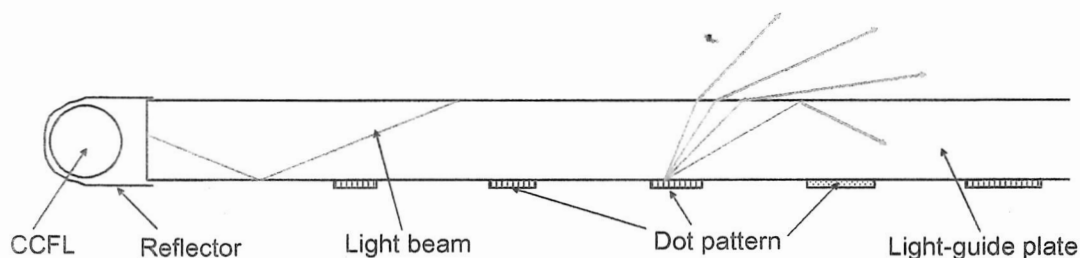


Figure 19.5 Edge-light guide: refractive index of air, $n_1 = 1.00$; refractive index of acrylate, $n_2 = 1.49$; critical angle $\theta_c = \sin^{-1}(n_1/n_2) = 42.2^\circ$.

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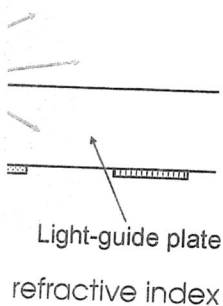
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Light-guide Plates

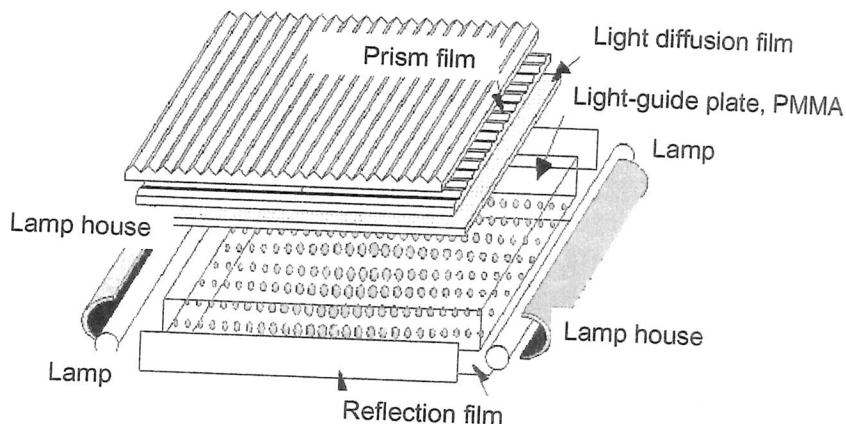


Figure 19.6 Example of edge-light type backlight unit.

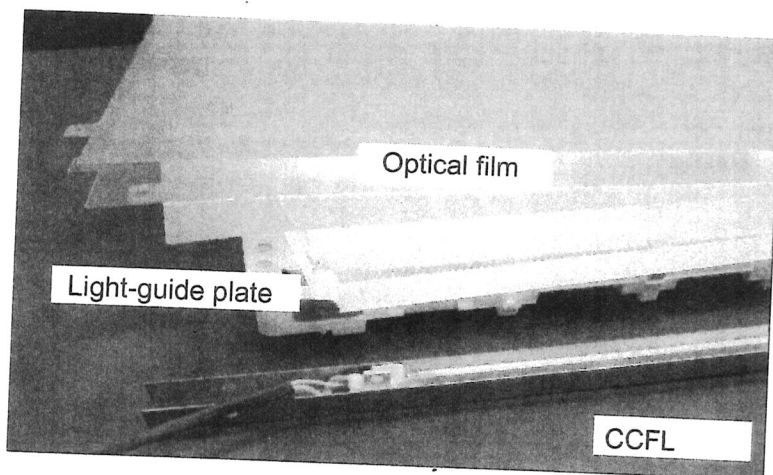


Figure 19.7 Structure of a 17-inch monitor.

The diffusion films play a role in eliminating the dot patterns from appearing on the LCD display.

19.5.2.4 Reflection Film

White color PET films are widely employed. The utilization of light is enhanced by stacking the reflection films on the back side of the light-guide plate, on which the dot pattern is printed.

19.5.2.5 Prism Films

Without the prism films, light from the backlight unit propagates not only in the perpendicular direction but also at oblique angles. By using prism

films the perpendicular component can be increased by 20%. For the prism films, PET films having a fine prism pattern are commonly used.

19.6 Characteristics Required for Materials of Light-guide Plates

There are two kinds of PMMA materials: one is a plate type, and the other is a pellet type used for injection molding.

19.6.1 Requirements for Plate and Pellet Mold Materials

19.6.1.1 No Extra Inclusions

Inclusions in the light-guide plates are the cause of mura (non-uniformity of luminance), bright spots and dark spots. When pellets are used, attention should be paid to inclusions coming from burned waste in the cylinder, extra resins, extra trash arising during the process of charging the material and burned wastes which adhere to the sliding part of the metal cast.

19.6.1.2 Colorless

Colorization of resins should be avoided since this results in color mura. For pellet molding, the plate becomes yellowish when there are residues of resin and depleted wastes in the cylinder. Sometimes dusts ingress during the molding process become the cause of an extra color formation. Invisible dust, which is accumulated in a hopper dryer, may cause degradation of the characteristics.

19.6.1.3 Excellence in the Optical Transmission over a Long Distance

PMMA is an excellent optical transmitting material. Nevertheless it is necessary to check the optical loss for light traveling a long distance, which may be degraded by colorization.

19.6.1.4 Durability at High Temperatures

The light-guide materials must withstand a temperature of 80°C, since the light-guide plates are positioned close to lamps to reduce the thickness of the backlight unit.

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19.6.2 Characteristics Required for Plate Materials

PMMA plates are supplied in the form of sheets. After they are cut, the dot pattern is printed on the surface. When the plates are being printed, uniformity of the patterns is required. Non-uniformity often arises from a curvature or uneven thickness of the plates. It is necessary to provide a flatness accuracy of ± 0.1 mm. Generally, PMMA has the property of absorbing water. Even a small amount of water absorption may cause a change in the dimension of a PMMA plate. Therefore it is necessary to cover the products by wrapping them with a high-quality film.

19.6.3 Required Characteristics for Pellets

19.6.3.1 High Fluidity

When fabricating a thin light-guide plate with a large area and having a prescribed shape, sufficient pressure should be uniformly applied to the material. Thus using a material having a high fluidity is desirable. The use of a high fluidity material also makes the plate free from deformation and cracks arising from printing inks, since the internal strain becomes less.

19.6.3.2 Low-temperature Casting

Casting at a low temperature yields desirable properties. As the molding temperature is lowered, the strain at the surface of the product becomes smaller, reducing bending of the plate. Also low-temperature production reduces coloration and degradation due to heating. However, a low-temperature process provides low fluidity. During the process of molding, the outer parts are cooled down first. Due to the low fluidity, only the outer parts become solidified. Then next, the inner parts are cooled down. This causes volume shrinkage in the inner part producing a volume density difference; this results in a higher refractive index in the outer part so that the light beams tend to be guided to the outer part. If we look at a light-guide plate from the opposite end, the image of an object looks smaller. Considering these effects, the low-temperature casting process should be controlled so as to assure the luminance balance.

19.6.3.3 Ease of Removing a Molded Material from a Cast

If the removal of a molded product from a cast is difficult, then the product yield becomes low due to deformation of the surface.

19.6.3.4 Protection from Humidity

Damp pellets produce silver-colored defects during the molding process. For this reason, damp pellets should be dried thoroughly in advance.

19.7 Materials for Extrusion Molding and Injection Molding

19.7.1 Materials for Extrusion Molding

The requirement for a light-guide plate is to guide the light through the plate and then to illuminate the whole the area of the plate uniformly without a significant loss of light. PMMA satisfies these requirements. Products, however, must be manufactured with a high level of quality control to eliminate any reduction in the luminance level and the appearance of bright spots which originate from the inclusion of dust or particles. Reduction in the internal strain is also important since it causes bending failure during environmental testing.

In order to provide a uniform optical output, a small amount of fine particles is doped uniformly in a light-guide medium as shown in Figure 19.8. The fine particles cause an enhancement of the optical throughput in the upward direction. Figure 19.9 demonstrates the result obtained by using light-scattering particles. Recently, research and development of advanced backlight units have been directed towards the integration of a light-guide plate with high-grade films such as light-diffusion films, converging lenses and reflection films. Advanced technologies such as multilayering, shaping and optical scattering have also been investigated.

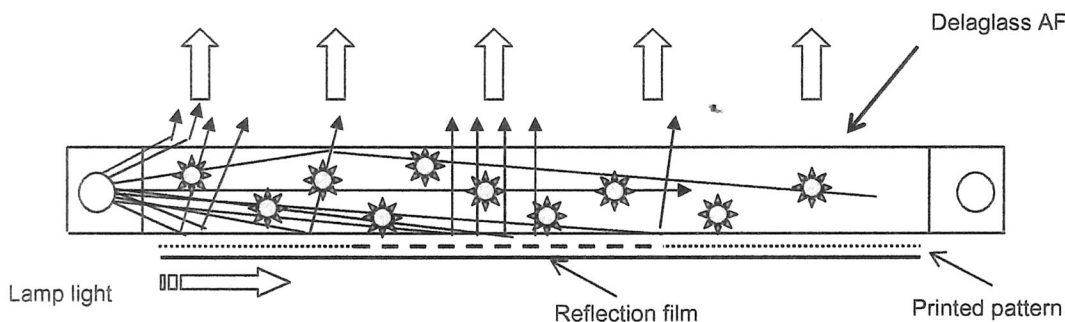


Figure 19.8 Scattering-type light-guide plate.

Figure 19.9 ing type c

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