OSRAM
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Light guides

Application Note

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Abstract

Light guides are used wherever the light of a light source should be distributed homogeneously over a larger area. Application examples using light guides include LCD backlighting for car dash boards, center information displays or door step illumination.

This application note provides information on various light guide designs and the use of LEDs as light sources for these light guides.

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A. Fields of application

Light guides are used in a wide range of applications. Below are some examples utilizing light guides:

- LCD backlighting, such as car radios, dashboards and navigation systems
- Status indication of electronic systems, road-marking, door step-marking, seat-marking, mood lighting and design light effects (handle bars, door panel and sealing, emergency light)

A light guide module is a combination of a light guide and a light source mounted on a substrate. LEDs are used as light sources, since their radiation angle and small package size is well suited for light guide applications.

This application note applies to a wide range of low-, mid- or high-power LEDs with a suitable radiation pattern for light guides.

B. Basic principle

To gain a better understanding of how light is guided into a light guide system, some fundamental theories must first be considered. A light guide is a transparent optical material designed to transport and distribute light. A light guide uses the mechanism of reflection caused by two materials with different refractive indices. It transports light from one location to another by means of total internal reflection at the boundary to the surrounding medium.

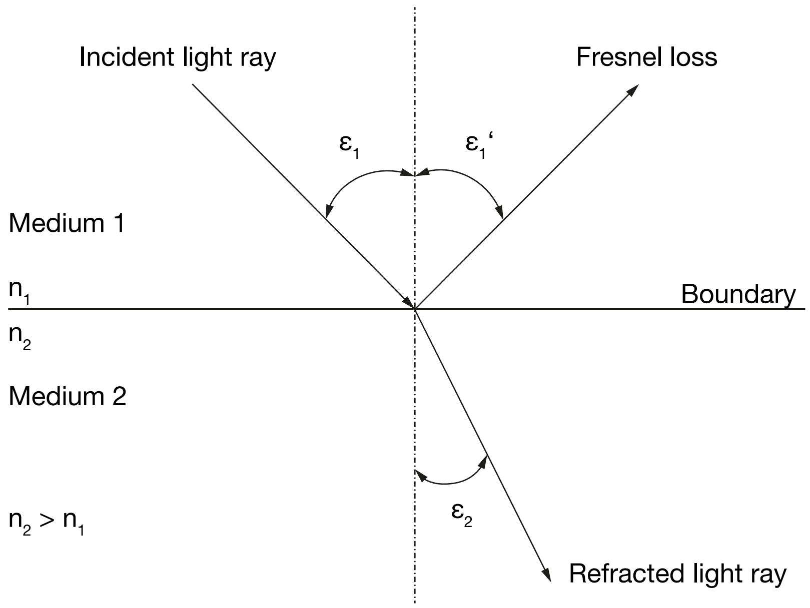
Imagine a light ray which hits the boundary at an incident angle (Figure 1). The boundary is the interface between two transparent optical materials. These materials have refractive indices designated as n_1 and n_2. Higher n numbers indicate higher optical material densities. Furthermore, the incidence angle is defined as ε_1, the refraction angle as ε_2.

Snell's law is defined as:

$$n_1 \cdot \sin(\varepsilon_1) = n_2 \cdot \sin(\varepsilon_2) \qquad (1)$$

Provided that a light ray is travelling from material n_1 towards material n_2 and that $n_1 < n_2$, this light ray is refracted towards the vertical line at the point of transition. If n_2 is more dense than n_1, the light ray is refracted towards the vertical line.

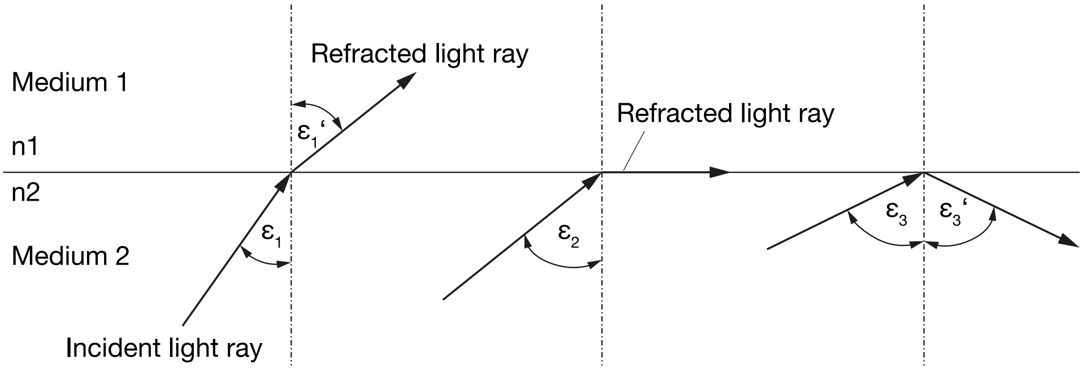
Figure 1: Light ray crossing through an interface at an incident angle



Total internal reflection:

If the refracted light ray is level with the surface of the two media, the incident angle ε_2 is defined as the critical angle ε_g (Figure 2, ε_2). For incident angles $\varepsilon_3 > \varepsilon_g$ the light ray is reflected back into medium 2. This situation is referred to as total internal reflection.

Figure 2: Critical angle



$\varepsilon_1 < \varepsilon_2$ -> exit for light ray
$\varepsilon_2 = \varepsilon_g$ = critical angle
$\varepsilon_3 > \varepsilon_g$ -> total reflection inside the light guide n2 > n1

The critical angle ε_g for the total internal reflection of the light ray is reached when the refraction angle is 90° to the vertical line respectively in-plane with the media's surface.

$$\sin(\varepsilon_g) = \frac{n_1}{n_2} \cdot \sin(90°) \qquad (2)$$

$$\varepsilon_g = \arcsin\left(\frac{n_1}{n_2}\right) \qquad (n_2 > n_1) \qquad (3)$$

The findings above are essential for light in-coupling into a light guide, light transport within a light guide and light out-coupling out of a light guide.

Fresnel loss:

At the boundary, losses are caused by reflection. These losses are referred as Fresnel loss.

$$\text{Fresnel loss} = \frac{(n_1 - n_2)^2}{(n_1 + n_2)^2} 100\% \qquad (4)$$

Fresnel losses at the boundary from air (refractive index = 1.0) to e.g. plastic (refraction index = 1.5) are 4 %.

The considerations above are fundamental for a light guide system. The light guide's function can be divided into the following parts:

- Light coupling into the light guide
- Light transport inside the light guide
- Light coupling out of the light guide

C. Light guide design

Coupling of LED light into a light guide

LEDs are well suited for high-performance light guide systems. The radiation pattern of top- or side-emitting LEDs is ideal for highest in-coupling efficiencies. Table 1 illustrates different possibilities for coupling LED light into a light guide. Advantages and disadvantages are listed.

Figure 3 illustrates the basics of a light guide system. A smooth surface at the light guide's in-coupling side and a small air gap between the LED and the light guide are important for efficient in-coupling

Figure 3: In-coupling and reflections

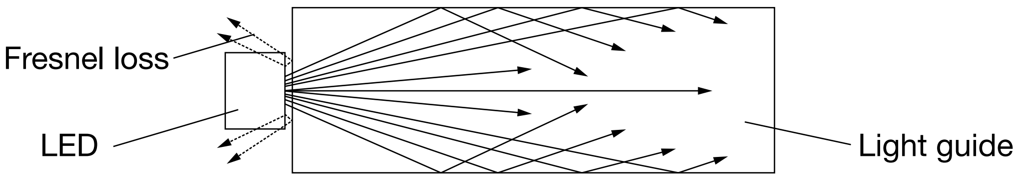
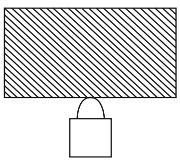
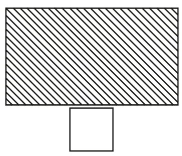
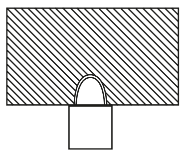
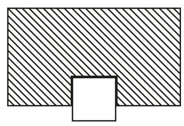


Table 1: Examples of LED light coupling into a light guide

LED on light guide		LED "embedded" in light guide	
Lens	**Flat**	**Lens**	**Flat**
			
Advantages			
Excellent light extraction from LED	Good light extraction from LED	Excellent light extraction from LED	Good light extraction from LED
	Good in-coupling into light guide	Best in-coupling into light guide	Good in-coupling into light guide
	Small air gap between LED and light guide	Small air gap between LED and light guide	Small air gap between LED and light guide
	Simple and com-pact design		Most compact design
Disadvantages			
Poor in-coupling into light guide		Complex light guide structure	Complex light guide structure
Space consuming LED		Longer mixing range inside light guide	Longer mixing range inside light guide

Properties of light guiding

In order to guide light inside a light guide, it is important to choose a material with a high refractive index and a high reflectance at the surfaces by means of smoothness.

Once the light has entered the light guide, it bounces between the top and bottom surface by the nature of the total internal reflection and keeps travelling until it hits an out-coupling structure or reaches the far end of the light guide. Rays not compliant with the rule of total internal reflection are extracted from the light guide. Such losses can be minimized by adding a specular film or white painted reflector to the small side and back surfaces.

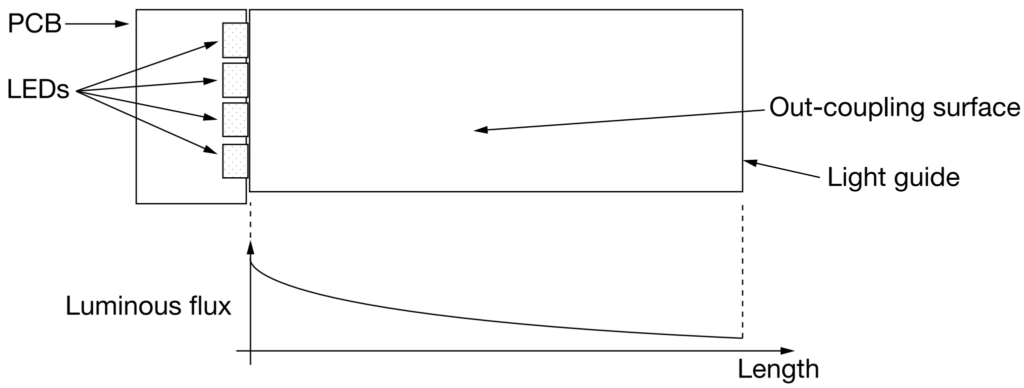
An additional reflector in level with the top and bottom surface at the in-coupling edge can help improving in-coupling efficiency.

Extracting light from a light guide

In order to extract light from a light guide an interruption of the smoothness of the surfaces is necessary. Such interruption points can be achieved by e.g. white dots printed on the bottom surface or small dents (mini/micro-lenses) applied to the bottom and/or top surface. These dents can be both convex and concave. At such spots light will be redirected in a diffuse or controlled directional manner and can escape from the light guide if it is no longer compliant with the rule of total internal reflection.

Figure 4 illustrates an application example. Light is coupled into the light guide at one side. The objective is to achieve uniform luminance over the entire out-coupling area. Hot spots at the in-coupling area and an intensity drop over distance towards the far end of the light guide require compensation by an out-coupling pattern.

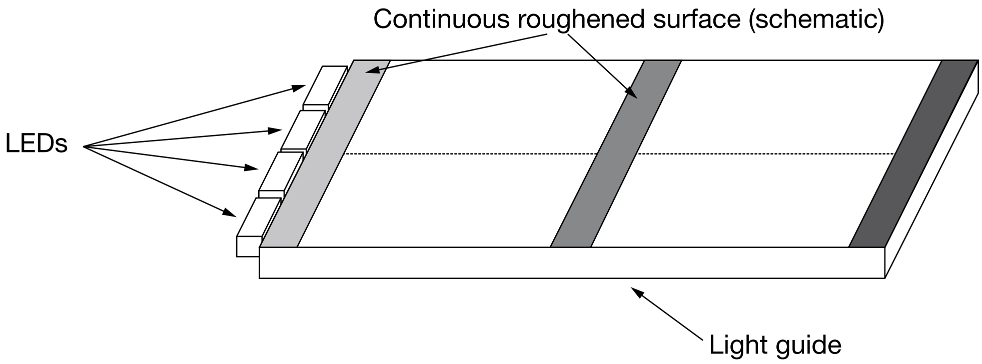
Figure 4: Example of a light guide (top view)



Roughened surface

A quick method for a prototype build can be surface roughening using sandpaper. Adjusting the grade of sanding over distance (strong at the far end, gentle at the in-coupling side) can compensate the luminance drop (Figure 5).

Figure 5: Roughened surface

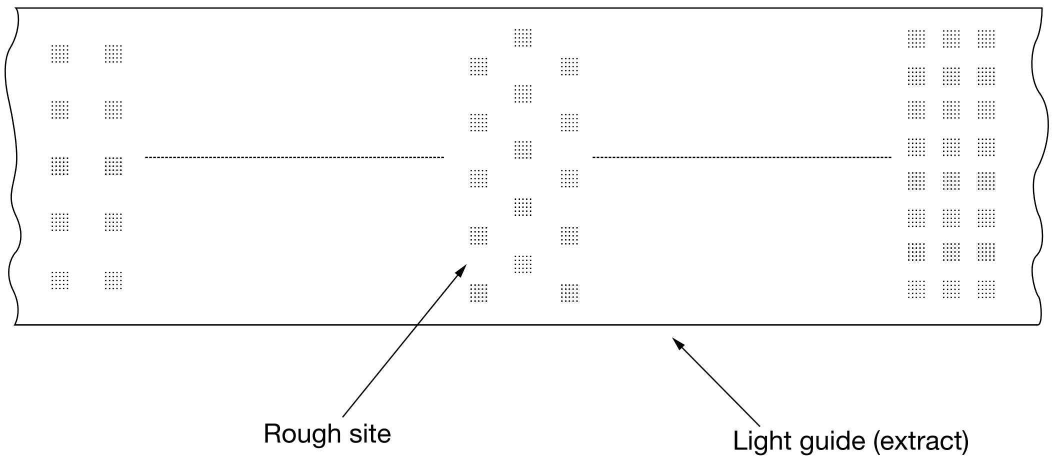


Dot structure on the backside

Another option is the application of small printed white dots on the backside of the light guide (Figure 6). The non-uniform light distribution inside the light guide can be compensated by varying the size and density of these dots over the entire area. Applying the dot structure at the bottom side of the light guide can help to reduce visible hot spots on the top surface.

The combination of both surface roughening and the printed dots results in highly homogenous luminance at the top surface. The addition of a white reflector sheet underneath the light guide can further enhance the optical efficiency of the entire system.

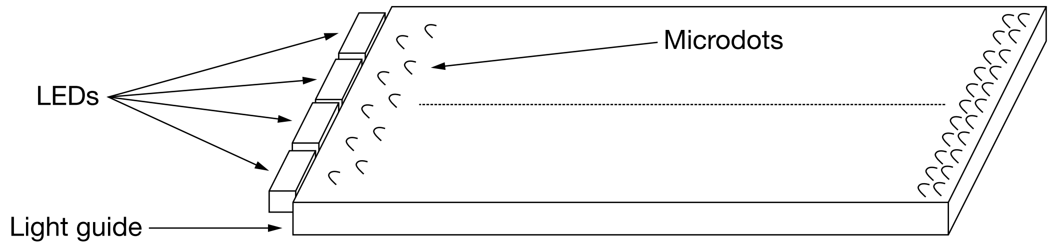
Figure 6: Dot structure on backside



Microdots

The imprinting or injection molding of hemisphere-like mini-dots or micro-dots at the bottom surface can replace the printed dots (Figure 7). Uniform luminance can be achieved by adjusting the density of dots per area and over the entire length of the light guide. In such applications it is essential to add a white reflector sheet beneath the dots. The dots can be applied to both the top and the bottom surface of the light guide, but mini-dots become less visible when applied to the bottom surface.

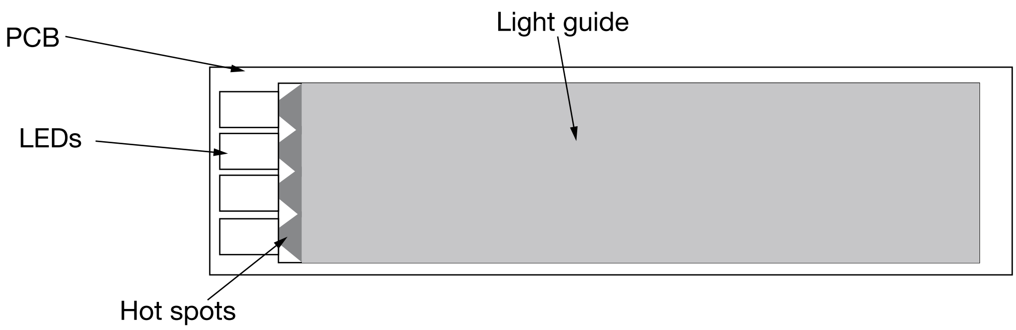
Figure 7: Microdots



Hot spots

At the in-coupling area, hot spots are caused by the radiation pattern of the LED (Figure 8). Hot spots are bright spots causing non-homogeneous regions at the in-coupling area. Depending on the radiation pattern of an LED, the LED pitch and the light guide design and material, such hot spots vary in size, intensity and extension inside the light guide. This hot-spot area is often referred to as the "mixing range" and must be considered in a light guide design as an overhead area which must be excluded from the application's "active area".

Figure 8: Hot spots



Diffuser

To achieve uniform light extraction from a light guide, it is also helpful to place a diffuser film on top of the light emitting surface. It can help to make the surface structure printed, molded or otherwise achieved, invisible. The back-scattering nature of such a diffuser further improves luminance homogeneity and reduces hot spots.

Setup variations

Possible setup variants are illustrated in Figure 9 and Figure 10.

Figure 9: Possible setup variations

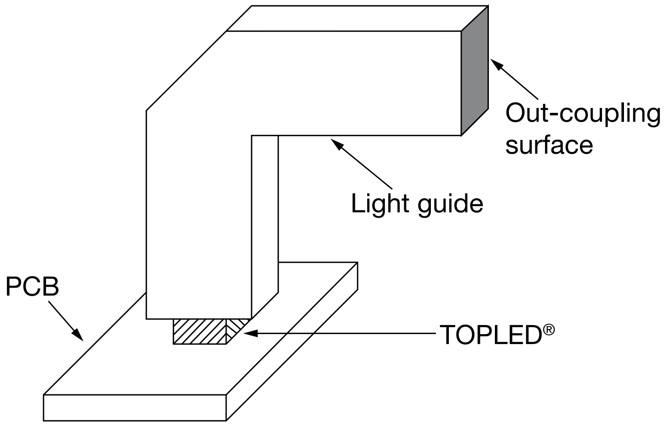
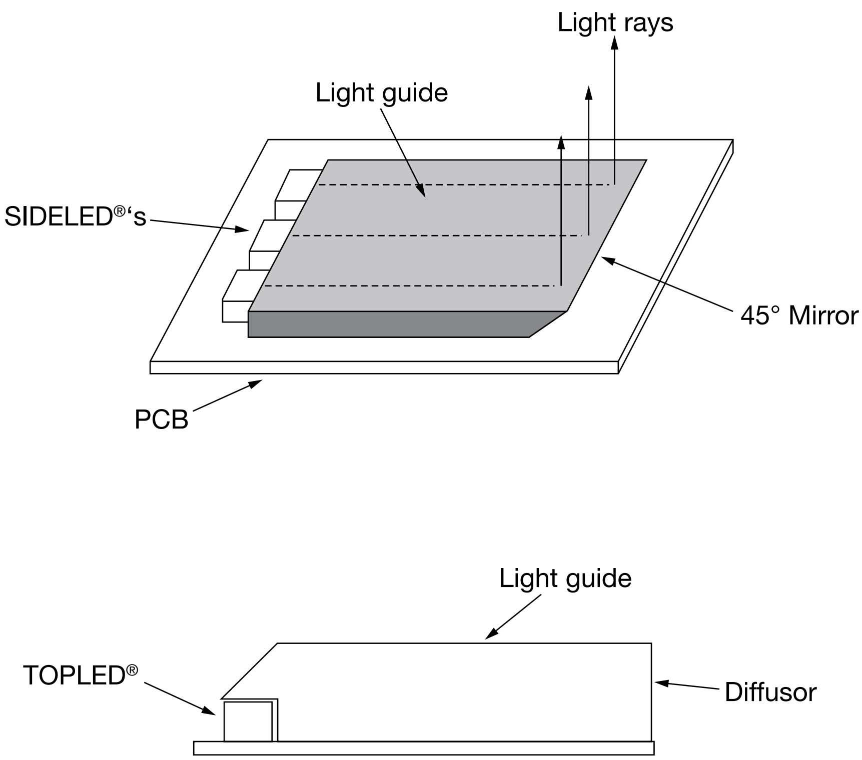


Figure 10: Possible setup variations



D. Summary

There are many ways to set up a light guide system with various LEDs from OSRAM. Depending on the application, top- or side-emitting LEDs can be used. They may be placed at the light guide edge or may be embedded. An important factor is the material of the light guide itself. A high refractive index, responsible for total internal reflection, is beneficial to achieving the best result.

Various properties of the light guide design determine the in- and out-coupling efficiency. Roughened surfaces, a dot structure on the backside, microdots or a diffuser are all helpful in achieving a uniform out-coupling area. Typically bright spots occur near the in-coupling area. This “mixing range” must be excluded from the “active area”.

Don't forget: LED Light for you is your place to be whenever you are looking for information or worldwide partners for your LED Lighting project.

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ABOUT OSRAM OPTO SEMICONDUCTORS

OSRAM, Munich, Germany is one of the two leading light manufacturers in the world. Its subsidiary, OSRAM Opto Semiconductors GmbH in Regensburg (Germany), offers its customers solutions based on semiconductor technology for lighting, sensor and visualization applications. OSRAM Opto Semiconductors has production sites in Regensburg (Germany), Penang (Malaysia) and Wuxi (China). Its headquarters for North America is in Sunnyvale (USA), and for Asia in Hong Kong. OSRAM Opto Semiconductors also has sales offices throughout the world. For more information go to www.osram-os.com.

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