SOURCES

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3.4 Light Emitting Diodes (LEDs)

It can be concluded from subsection 1.3.2, describing how a diode generates light, that its luminous efficacy depends on the wavelength of the produced visible radiation. However, there are other influencing factors, like the current and losses in the diode. The latter are caused by the absorption to which every light ray is exposed before leaving the diode. As a result of a high refractive index which characterises most semiconductors, a significant part of light that reaches the diode surface returns to its interior (total reflection, shown in **Fig. 3.15a**). After a number of such reflections, light rays, greatly weakened, leave the diode.

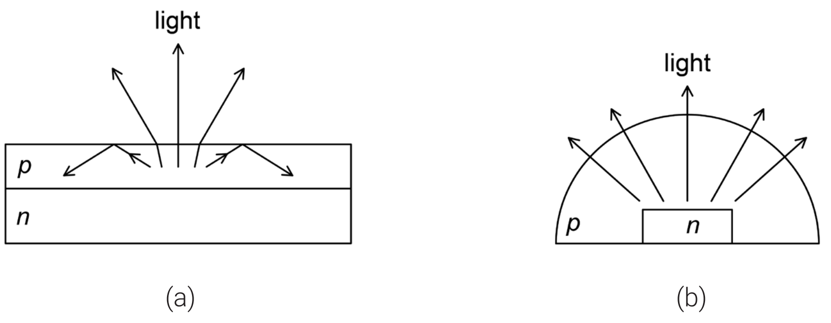

Figure 3.15 Classic construction of a diode with an extensive total reflection (a) and a novel solution by which total reflection is significantly reduced (b)

In order to reduce the total reflection, the p-type semiconductor material is produced in the form of a dome (as in **Fig. 3.15b**), causing most of incident angles at the diode surface to be smaller than the critical angle, defined in subsection 1.5.2.1.

The diode (LED chip) is always placed inside a plastic capsule, which represents the primary optics of LED luminaires (a combination of an LED chip and capsule is called an LED package).

Plastic capsules can be either diffuse, when emitting light in all directions, or transparent, when light is directed by means of a lens surrounding the capsule. Such lenses represent the so-called secondary optics of LED luminaires. **Figure 3.16** shows examples of light patterns (WE-EF LEUCHEN 2011), which, due to lenses, are formed on a roadway surface.

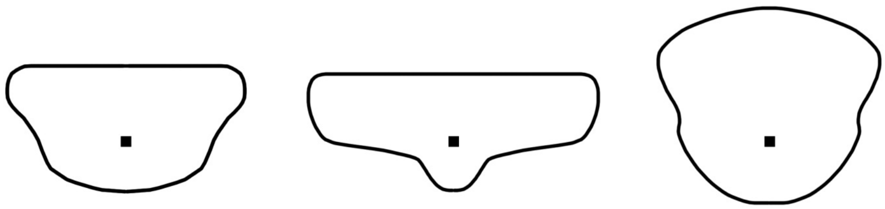

Figure 3.16 Examples of light patterns on a roadway surface formed by LED luminaires

In order to provide protection of an LED luminaire against dust and water, along with secondary optics (lenses) an outer optical cover made of glass or transparent plastic resistant to ultraviolet radiation (the tertiary optics) is frequently applied (**Fig. 3.17**). There were some attempts to construct LED luminaires without outer optical covers. However, experiments showed that in such cases dust deposited on the lenses not only reduces the luminaire luminous flux, but also significantly changes its luminous intensity distribution (polar diagrams) – see Section 4.5.

Figure 3.17 An LED luminaire with lenses and an outer optical cover

An essential part of every LED luminaire is an electronic device (the so-called driver), the role of which is the production of the DC current necessary for powering the diode. Programmable drivers additionally enable the diode luminous flux control.

3.4.1 White light LEDs used in street and ambient lighting (Liu et al. 2007; ILE 2009; Archenhold 2010; Bando 2011; Hunt et al. 2014; Hecht 2016)

Although research related to LED chips had lasted for decades, not until 1993 has the decisive progress been made that would enable mass application of LED technology in both indoor and outdoor lighting. At that time a high-brightness blue LED chip was constructed, which, with the previously developed red and green chips, completed a set of three primary colours, the combination of which provides the possibility to produce an unlimited number of colours. Combining the three chips (RGB), white light was obtained. In addition, a blue LED chip was the basic element for the construction of white light LED packages, representing the main goal of LED technology from the very beginning. Specifically, coating the inside of a blue LED chip capsule with special luminescent substances that provide acquisition of the remaining colours of the spectrum, the white light LED packages with good colour rendering properties were produced. In the beginning, they were characterised by a high correlated colour temperature (cool white (or blue-rich) LED packages). It did not take long until neutral white and warm white LED packages were produced.

At present there are three methods for obtaining white light using LED technology:

- applying a yellow luminescent material to the capsule of a blue LED chip,
- applying one or more luminescent materials to the capsule of an LED chip that emits light near the ultraviolet part of the spectrum, and
- combining at least three different-coloured diodes which jointly produce white light.

The first method is most frequently used, primarily for economic reasons. By its application, a white light LED package is most frequently obtained by coating the capsule of a blue diode (InGaN) with a yellow luminescent substance (YAG – Yttrium Aluminum Garnet) (Bando 2011). The curves of its spectral power distribution (shown in Fig. 3.18 for three CCT ranges) have a sharp peak in the blue part of the spectrum (440–460 nm) and a flattened peak in the green/yellow or orange part of the spectrum (540–575 nm and around 610 nm, respectively).

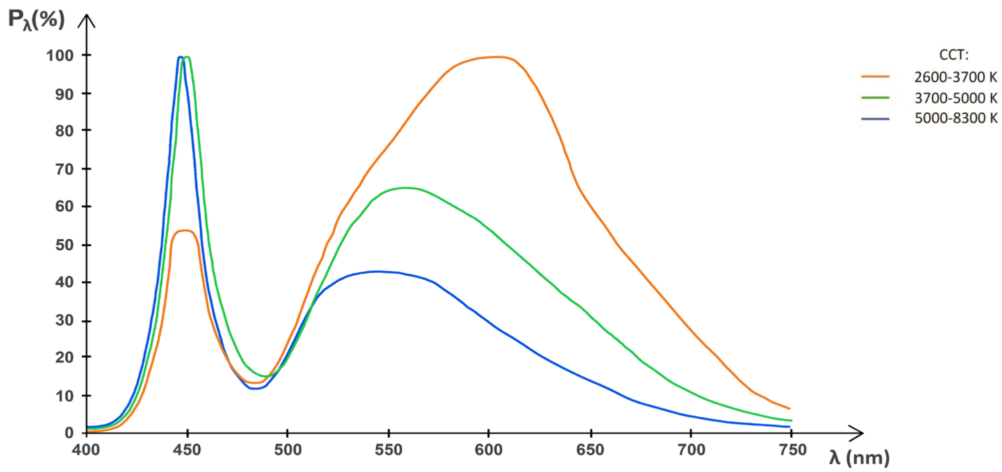

Figure 3.18 Typical relative spectral power distributions of white light LED packages

With constant improvements of the diode characteristics, luminescent substances and capsules, by 2020 the luminous efficacy of white light LED packages has increased from 5 lm/W to even 300 lm/W (its maximum theoretical value for RGB LEDs is evaluated to be 355 lm/W (Liu et al. 2007)). Recently, the leading manufacturers of LED packages reported that commercially available neutral white LED packages of the latest generation would provide about 190 lm/W.

Since diodes (including white light ones) do not emit infrared (heat) radiation, the produced heat can be transferred to the environment only by conduction or convection (surrounding fluid flow). This is why heat dissipation represents one of the major problems faced by constructors of LED luminaires. Insufficient heat dissipation leads to an increase of the junction temperature, which reduces the luminous flux and, particularly, lifetime of the diode (junction temperature is the temperature of the joint of the diode and the carrier attached to the electrical panel containing the wiring). (Archenhold 2010)

Leading manufacturers of LED packages generally declare the lifetime of an LED package as the time during which its luminous flux drops to 80% or 90% of the initial value (for example, a designation 100,000 hours L80B10, frequent for LED packages, means that after 100,000 hours maximum 10% of the considered LED packages will have luminous flux lower than 80% of its initial (rated) value). Some independent studies have shown that the lifetime declared by manufacturers (usually 50,000–100,000 hours) can only be achieved if the junction temperature is not higher than 70 ºC. For example, if the junction temperature frequently reaches 100 ºC (which can occur in geographic locations with a high ambient temperature) the diode lifetime may be reduced to only 20,000 hours. (ILE 2009)

The LED lifetime declared by the manufacturers represents a mathematical estimation. It is obtained by extrapolation of the relevant curve (luminous flux versus time), gained by laboratory measurements usually lasting for 6000 to 10,000 hours only.