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Details on photobiological safety of LED light sources

Application Note

Valid for:
all visible LEDs from OSRAM Opto Semiconductors

Abstract

This application note provides a brief insight into the safety implications for the eyes regarding LED light sources emitting visible optical radiation. The application note points out relevant standards and specific limit values and presents general grouping of current OSRAM Opto Semiconductors LED products.

Further information:
For information regarding infrared LEDs please refer to the application note “Eye safety of IREDs used in lamp applications”.

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A. LED light sources

The phasing-out of incandescent lamps in the EU and many other countries elsewhere and the introduction of many new LED sources have raised questions in the market regarding the eye safety of this technology.

Of particular interest — and the object of particular scrutiny — are high-power or high-brightness LEDs, whose luminous efficacy and brightness are in many cases equal or even exceed the traditional technologies.

LED light sources have similar characteristics to traditional technologies such as incandescent lamps and fluorescent tubes in terms of photobiological safety and should not be evaluated as being any different. Commercially available LEDs and light sources assembled from LEDs are accordingly safe when mounted and used in accordance with the applicable standards and regulations.

In applications in which people may look straight into bright and powerful point-like light sources from a short distance special care must be taken. However, this applies equally to all light sources, not only LEDs.

Note: It should be kept in mind that this application note relates exclusively to OSRAM Opto Semiconductors LEDs in the 380 nm to 780 nm wavelength range for non-pulsed operation.

B. Classification of LEDs per relevant standards

There is still a certain anxiety, or at least skepticism, surrounding the whole issue of the potential hazard posed by the use of LEDs and products containing LEDs. This uncertainty among users is based on a lack of detailed knowledge of LED technology and from the high luminance of these miniature light sources. The situation has been exacerbated by the fact that for most of the last few decades, LEDs fell under the IEC 60825 standard — the international standard for laser safety — and consequently had to be classified and grouped like lasers in relation to eye safety.

This subsequently having been recognized as an too restrictive assessment, today all LEDs without restriction are subject to the optical radiation safety regulations for incoherent broadband optical sources. Now, LEDs are consequently evaluated and categorized in terms of optical safety in accordance with the photobiological safety standards for lamps and lamp systems:

- IEC 62471 (International) / EN 62471 (EU) [1]
- ANSI/IESNA RP-27(USA) [2]

These standards define four different Risk Groups for LEDs as well as lamps.

The most significant influence factor is the time basis (exposure period) varying for each group: the higher the Risk Group, the shorter the time basis to be applied. The assigned wavelength-dependent limit values for radiance [W/(m² sr)] and irradiance [W/m²] are increasing for higher risk groups.

Table 1 gives an overview of the data relevant to LEDs according to IEC 62471 and the safety factors underpinning the Risk Groups. Not shown in the table is Risk Group 3 (RG 3), which is for high-risk optical radiation sources that can represent a hazard, even with short exposure times.

The assignment of an LED to a particular Risk Group indicates that the limit value concerned must not be exceeded over the specified exposure period subject to a minimum distance of 200 mm.

This standardized evaluation and measurement distance of 200 mm is a worst-case assumption, as exposure — a direct gaze into a light source — will rarely take place at such short distances and especially not for anything approaching a prolonged period (see also Technical Report IEC TR 62471-2) [3].

Table 1: Overview of the risk groups according to IEC / EN 62471 and the data of relevance to LEDs, including the applicable emission limits

Risk Group	**Safety message**	**Exposure periods to determinate (emission limits)**	
		Retinal photo-chemical hazard	**Retinal thermal hazard**
Risk Group “exempt” (RG 0)	No photobiological hazard	10,000 s (100 W/(m^2 sr)) (1 W/m^2)[1]	10 s (28,000/α W/(m^2 sr))
Risk Group “low risk” (RG 1)	No hazard due to normal behavioral limitations on exposure	100 s (10,000 W/(m^{2}sr)) (1 W/m^2)[1]	10 s (28,000/α W/(m^2 sr))
Risk Group “moderate” (RG 2)	No hazard due to the aversion response to very bright light sources or due to thermal discomfort	0.25 s (4 x 10^6 W/(m^2 sr)) (400 W/m^2)[1]	0.25 s (71,000/α W/(m^2 sr))

[1] Emission limit for small sources with radiation power

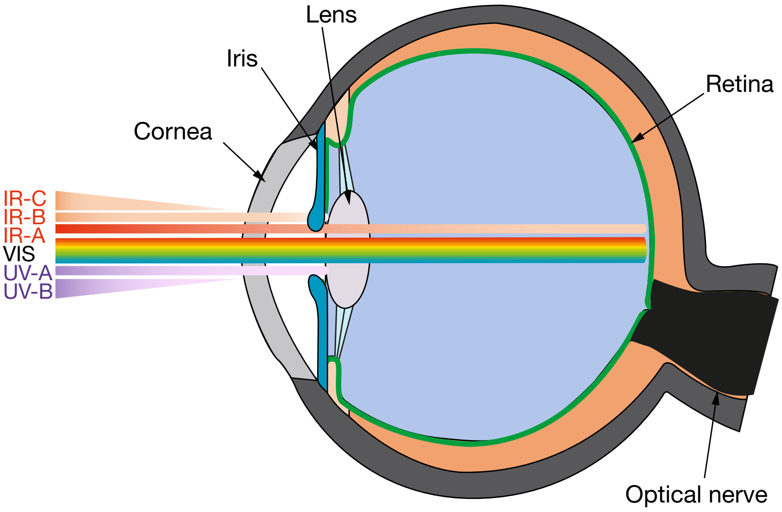
C. Possible hazards from light

Visible light (380 nm to 780 nm) can damage the eye by thermal or photochemical effects. Due to the different transmission and absorption characteristics of the various components of the human eye (Figure 1), the biological effect on the eye and the relative potential hazard depend strongly on the wavelength of the incident radiation (Table 2).

Table 2: Possible hazards with corresponding wavelength range

Kind of hazards	**Biological action spectrum**	**Wavelength range**
Retinal thermal injuries	R(λ)	380 — 1,400 nm
Blue light hazard	B(λ)	300 — 700 nm

Figure 1: Penetration of optical radiation into the eye

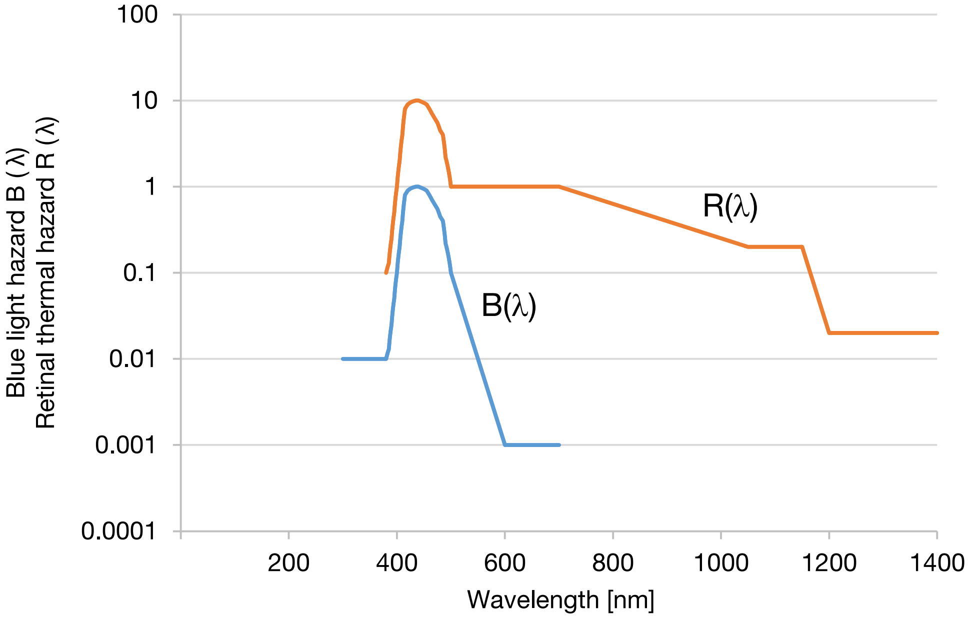


This spectral dependence can be illustrated and described using special action and weighting functions.

Figure 2 shows the function curves for the "retinal thermal" (R(λ)) and "retinal photochemical" (B(λ)) hazard types of relevance for LEDs.

The occurrence and the extent of the possible damage are generally determined by factors such as the duration of exposure, the area of the retina exposed (dilation / source dimensions) and the radiance of the light source.

Figure 2: Spectral weighting curves for the B(λ) and R(λ) retinal hazard



Retinal thermal hazard

Thermal damage to the retina — essentially overheating of retinal tissue — is caused by the energy of the incident light being absorbed into the tissue, eventually resulting in a temperature increase and localized burning. The extent of the damage depends on the size of the area affected and the temperature reached, with irreversible damage occurring only beyond a certain critical value.

In principle, even a very short exposure time (< 10 s) can be sufficient to cause thermal damage, but only if the effective incident power density is very high. The photochemical mechanism (photoretintis) dominates over the thermal effect for exposure times exceeding 10 s.

Blue light hazard (photoretinitis)

The photochemical retinal hazard involves a photochemical process in which highly energetic short-wave radiation causes damage, in some cases irreversible, to the retina.

The main area of concerns lies between 400 nm and 500 nm (= blue light). The critical aspect in terms of the harm potential however is not the blue component itself, but rather the energy content in this range of the spectrum, which depends essentially on the luminance (effective blue light radiance).

Gazing up at a blue sky (very high proportion of blue light, but scattered, so luminance low), for example, is completely harmless, but even very brief exposure to direct sunlight, which has a very high radiance, can lead to damage.

The radiation absorbed — which depends on the intensity of the incident light and the length of exposure — causes photochemical decomposition of the pigments present in the photoreceptor cells. The photopigment fragments thus created act as free radicals, leading to the death of the photoreceptor cells.

Glare

Intensive visible radiation can also affect the vision without actually causing permanent damage to the eye, for example with what is known as glare. There are two distinct types of glare: discomfort glare, which causes an unpleasant sensation, and disability glare, which degrades visual acuity. Glare is caused by excessive differences in luminance or unfavorable luminance distributions at the eye (see also DIN EN 12665 [4]). The phenomenon of glare does not itself cause direct damage to the eye, but can lead to harm indirectly by impairing vision and the ability to recognize objects, which poses an obvious risk to anyone driving a vehicle or operating machinery, for example. The extent of glare is determined largely by the state of adaptation of the eye.

There is generally no fundamental difference in terms of glare between LEDs and other synthetic or natural light sources, so this aspect is not considered in any more detail here. Further information including a quantitative description of glare can be found in the DIN EN 12464 standard (Light and lighting — Basic terms and criteria for specifying lighting requirements) [4] and in the related technical literature.

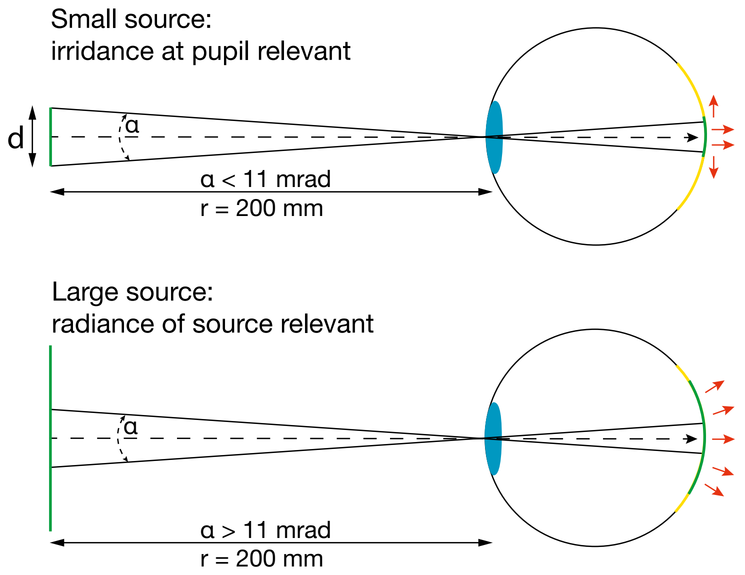
D. LED risk assessment

It is essential when analyzing the potential hazard posed by LEDs to bear in mind that biological action depends on the wavelength of the optical radiation (spectral weighting function B(λ) and R(λ)) and on the size of the light source and of the retinal surface affected.

The standards differentiate between large sources and small sources. The image of a small source (angular subtense < 11 mrad) will be smeared over a larger area of the retina due to voluntary and involuntary eye movements at longer exposition times. This results in a reduced risk of retinal damage. The definition of a small source is a maximum source diameter of 2.2 mm at a distance of 200 mm, e.g. LEDs of OSRAM Opto Semiconductors having one chip and a maximum active area of 2 mm² belong to this category.

The blue light irradiance E_B has to be used to calculate the maximum exposure time and to determine the resulting classification into Risk Groups due to the smearing effect. This is proportional to the effective irradiance at the retina.

Figure 3: Significance of source size

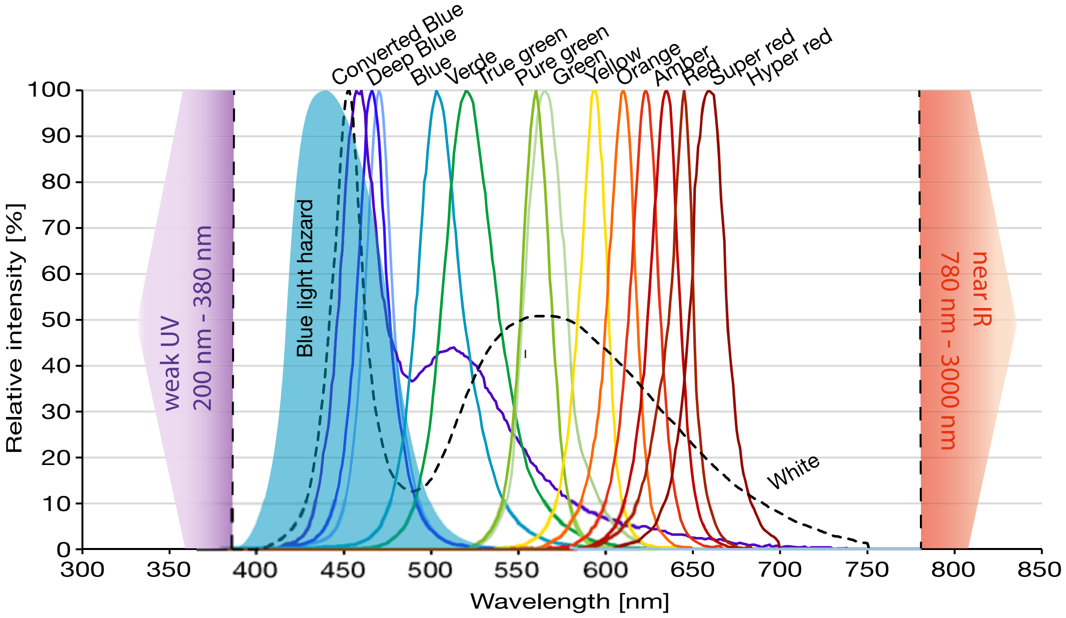


LED designs with a larger chip surface or multiple chips in combination (a chip array) are assigned to the "extended" or "large" source category. According to the standard, these light sources must be classified by their blue light radiance (L_B), a quantity derived from the density of the radiation in the relevant blue light hazard (BLH) action spectrum.

Extended sources include e.g. the LED arrays OSLON® Black Flat with multiple chip configurations and the OSRAM OSTAR® Projection Power with chip size of e.g. 6 x 2 mm².

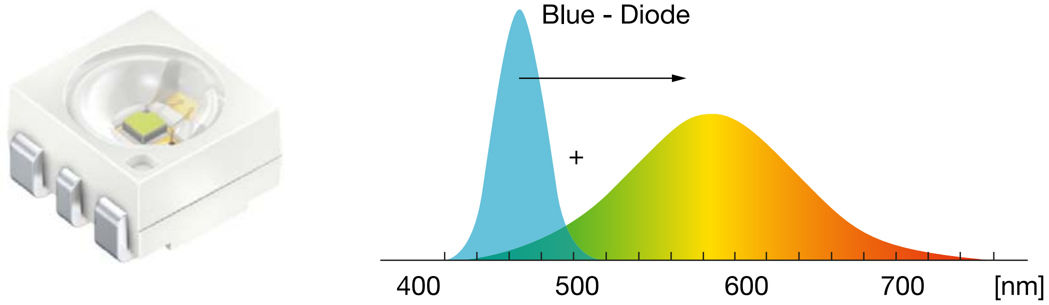
The blue light hazard posed by LEDs is of concern in particular for certain colors including Converted blue, Deep blue, Blue, Verde, True green, Pure green and Green, whose spectra lie within the range of relevance for photochemical action (Figure 4).

Figure 4: Typical spectra of high-power LEDs from OSRAM Opto Semiconductors



Typical white LEDs also fall into the blue light hazard area owing to the pronounced peak in their spectrum in the blue range around 450 nm. This is a direct consequence of the way that white LEDs are made: usually they comprise a semiconductor diode that emits blue light plus one or more phosphors. The phosphors absorb and convert a proportion of the blue light such that the light ultimately emitted by the LED is perceived as white (Figure 5).

Figure 5: Typical white LED and principle of white conversion



The nature and composition of the conversion material determines the spectral quality of the light emitted, allowing different tones to be realized as required. The range of white tones achievable extends from cold white or daylight white (containing a greater proportion of blue, Correlated Color Temperature CCT > 5,000 K) to neutral white (5,000 K > CCT > 3,300 K) to warm white (containing a greater proportion of red, CCT < 3,300 K), with specific spectral distributions.

The larger the CCT value of the white tone, the higher the proportion of blue light will be in the radiation emitted.

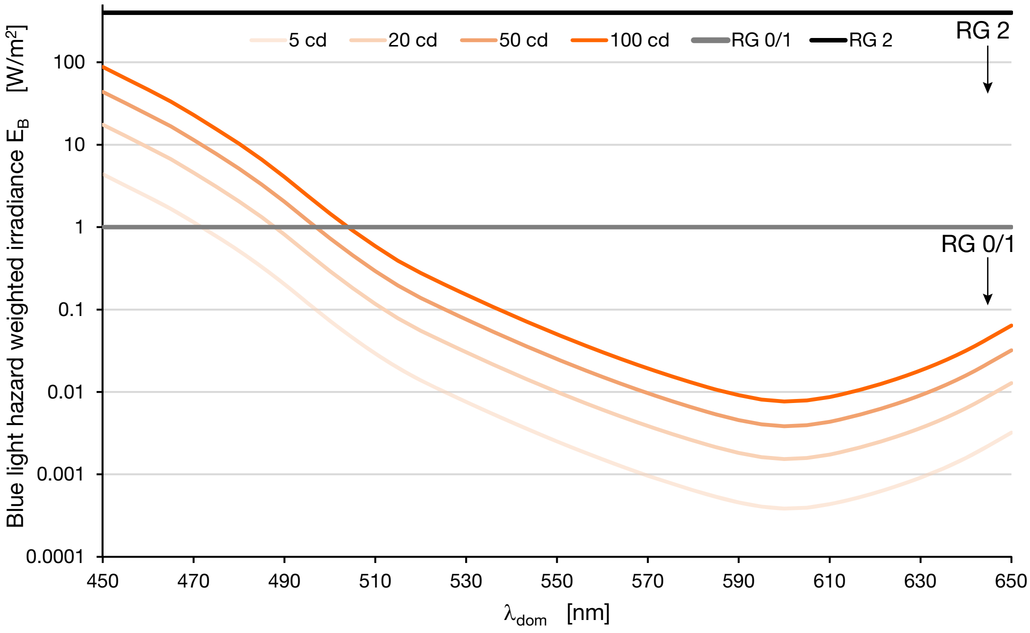
In contrast, the thermal hazard potential is primarily of concern for LEDs with wavelengths in excess of around 560 nm, which takes in colors such as (Yellow, Amber, Red, Super red and Hyper red. However the effect is so small as to be negligible for wavelength below 560 nm.

E. Optical safety evaluation

While all OSRAM Opto Semiconductors LEDs intended for general illumination applications are subject to certified eye safety measurements, they can also undergo a general evaluation and classification process. This involves determining the weighted irradiance (for the blue light hazard) and the weighted radiant intensity (for the thermal hazard) for the various single-chip LEDs on the basis of their typical spectra. The calculations are based on luminous or radiant intensity in order to exclude possible component lensing effects. The calculated curves can then be used to perform a basic evaluation and classification of the various single-chip LEDs from OSRAM Opto Semiconductors.

Figure 6 presents four curves with irradiance figures of relevance in terms of blue light hazard for specified luminous intensities (5 cd, 20 cd, 50 cd and 100 cd) as a function of wavelength and also shows their progression and their position in the risk group system. A blue LED with a luminous intensity of 5 cd or 20 cd and a dominant wavelength of 470 nm, for example, falls into Risk Group 2.

Figure 6: Blue light hazard weighted irradiance of single-color LED (small source)



In contrast, Figure 7 shows three curves for the blue light hazard weighted irradiance corresponding to different radiant intensities. This takes into account that some LEDs from OSRAM Opto Semiconductors (especially Deep blue) are grouped according to the radiant intensity.

Figure 7: Blue light hazard weighted irradiance of Deep blue till Blue LEDs (small source, calculation based on radiant intensity)

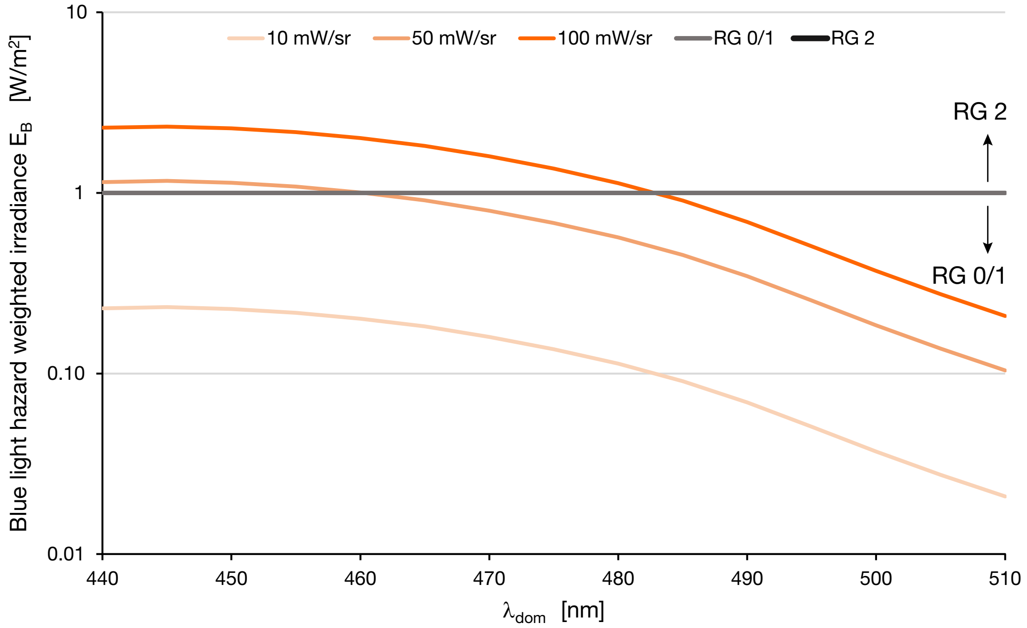


Figure 8 shows individually calculated values plus three trend curves for blue light hazard weighted irradiance as a function of the color temperature (CCT) of the white point along with the progression of the curves and the position of the selected examples in the risk group system. The figures relate to three different luminous intensities: 20 cd, 50 cd and 100 cd. Figure shows the typical spectra of Warm white, White and Ultra white LEDs to provide context and help with interpretation of the chart in Figure 8.

Figure 8: Blue light hazard weighted irradiance of White LED (small source)

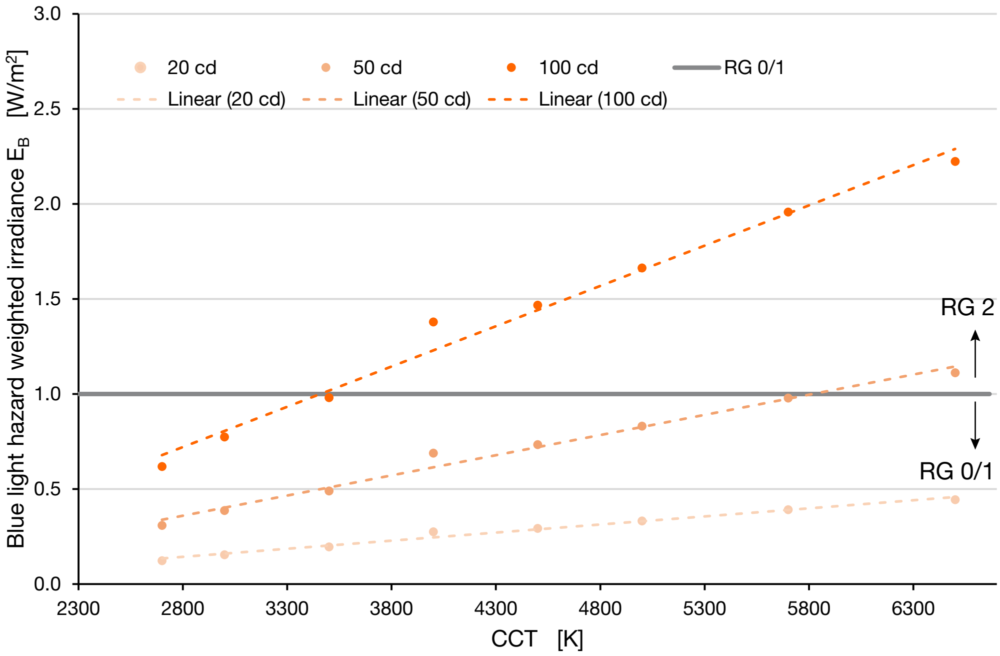


Figure 9: Typical spectra of White LEDs

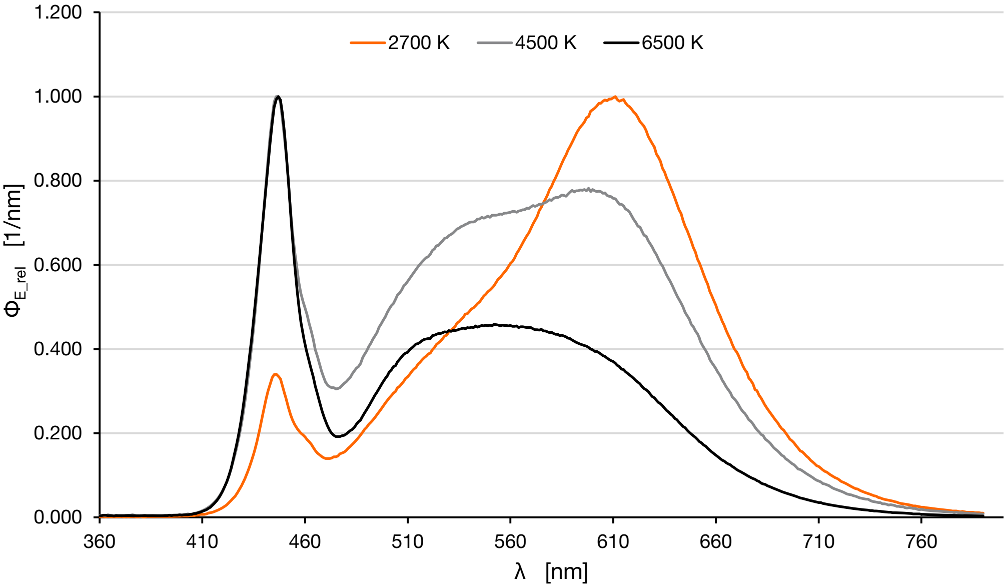
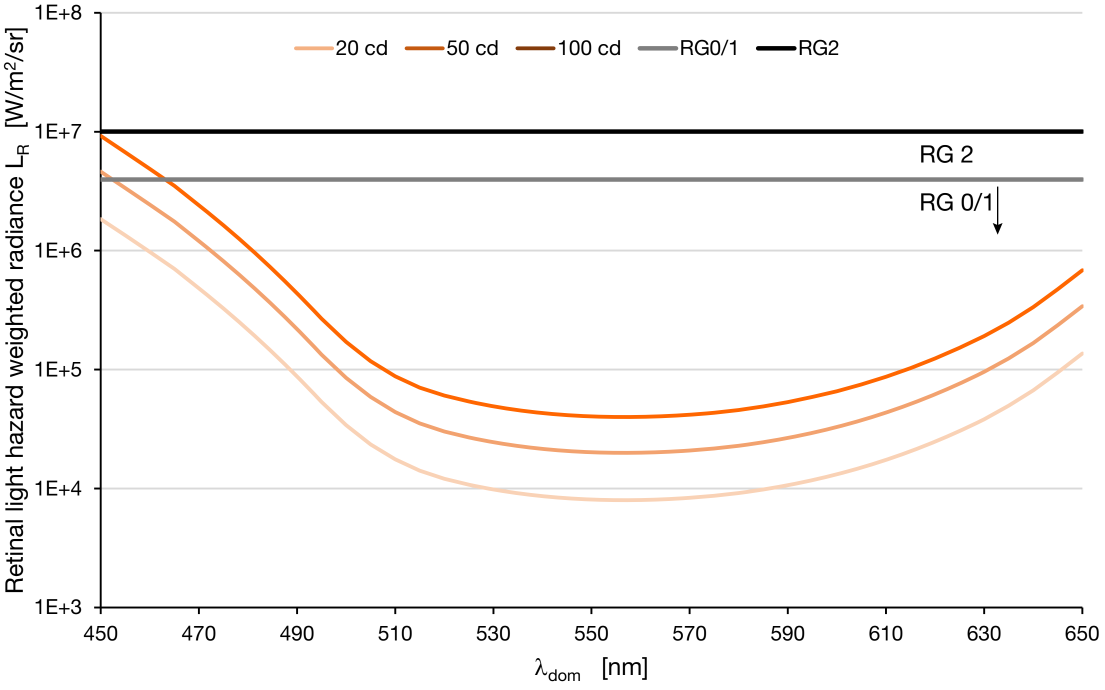


Figure 10 shows for small sources three curves indicating weighted radiance for the retinal thermal hazard as a function of wavelength.

Figure 10: Retina thermal hazard weighted radiance of single color LED (small source)



Example. Model calculation for evaluating the retinal thermal hazard L_R of a red LED (small source) with a wavelength of 615 nm and a luminous intensity of 100 cd. An LED of this type, as the calculation shows, would fall into the "Exempt" risk group (RG 0).

Retina thermal hazard (L_R):

• General threshold of Risk Group “Exempt”	$28{,}000/\alpha$ [W/(m^{2}sr)]
• Maximum permissible value of RG 0/1 for LEDs with 2 mm² chip area (1.4 x 1.4 mm) [α = d / r = 1.4 mm / 200 mm = 0.007]	$4*10^6$ [W/(m^{2}sr)]
• LED with λ_{dom} = 615 nm	
• Luminous intensity = 100 cd	
• Weighted radiance $\mathbf{L_{R,\ 615\ nm,\ 100\ cd}}$	$< 2*10^5$ [W/(m^{2}sr)]

F. Conclusion

A basic assessment of the high-power LEDs currently available from OSRAM Opto Semiconductors in accordance with the IEC / EN 62471 standard shows that single LEDs in the colors Yellow, Orange, Red and Hyper-red typically fall into Risk Group 0. For specific information on the risk group please refer to the respective data sheet. Consequently, at the moment there is no need for an individual, design-specific safety assessment of LEDs in the spectrum range of 510 nm $\leq \lambda_{dom} \leq$ 660 nm, based on existing semiconductor technology.

In contrast, blue and green high-power LEDs (450 nm $\leq \lambda_{dom} \leq$ 510 nm), which pose a risk of photochemical damage to the retina, can produce radiation parameters sufficiently hight to qualify for Risk Group 2, depending on the spectral composition of the light emitted. However, even LEDs classified in Risk Group 2 pose no risk according to the standard, when used as intended in the case of an accidental glance into the light source, because ordinarily this just triggers the natural protective reflex (either closing or averting the eyes).

LEDs realized using current semiconductor technology generally do not fall into Risk Group 3 (hazard with short exposure time).

OSRAM Opto Semiconductors supports customers in their development and design process to help them find the best solution for specific applications. Thus the risk grouping is stated in the data sheet of the product. Technical reports for our LED types are available on request in this connection.

For further information or queries, please contact your sales representative or OSRAM Opto Semiconductors.

G. References

[1] IEC 62471:2006, modified, Photobiological safety of lamps and lamp systems.

[2] ANSI/IESNA RP-27 series, Photobiological Safety and Risk for lamps and lamp systems.

[3] IEC TR 62471-2, Photobiological safety of lamps and lamp system — Part 2: Guidance on manufacturing requirements relating to non-laser optical radiation safety.

[4] DIN EN 12655:2011-09: Light and lightning — Basic terms and criteria for specifying lighting requirements.

[5] RL 2006-25-EC, Directive 2006/25/EC of the European Parliament and of the Council of 5 April 2006 on the minimum health and safety requirements regarding the exposure of workers to risks arising from physical agents (artificial optical radiation, 19th individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC).

[6] CELMA LED (FR) 003A, Annex A to joint CELMA / ELC Guide on LED related standards: Photobiological safety of LED lamps and lamp systems.

[7] CELMA-ELC LED WG(SM)001_ELC CELMA Optical safety of LED lighting, 1st Edition July 2011.

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[10] AUVA, M083, Optische Strahlung: Sicherheitsbeurteilung von LEDs — sichtbare Strahlung. https://www.auva.at/cdscontent/load?contentid=10008.544575&version=1527097141

[11] Künstliche optische Strahlung — Evaluierung der biologischen Gefahren von Lampen und Lasern, Leitfaden, Vienna, July 2010.

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[14] H.-D. Reidenbach, K. Dollinger, G. Ott, M. Janßen, M. Brose, Blendung durch optische Strahlungsquellen. 1. Auflage, Dortmund: Bundesanstalt für Arbeitsschutz und Arbeitsmedizin, 2008.

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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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