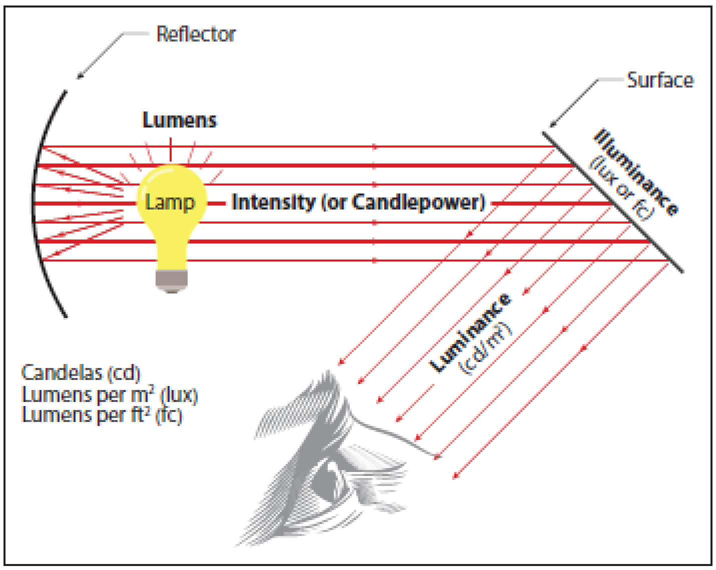
Curved vs. Flat Source Emitter

The invention of a flat surface device that emits visible radiation has created a new class of light source that requires a different set of metrics from curved surface light sources.

Curved Surface Emitter

Figure 1 is a diagram of basic lighting terms from the Illuminating Engineering Society. As can be seen in the diagram, the lamp emits uniform energy in all spatial directions, eventually entering the eye with spatially uniform (isotropic) energy. The metrics for the light entering the eye from the flat surface is called luminance and is measured in candela per square metre, also known as nits.



Relationship of basic lighting terms.

Figure 1

The brightness of the lamp is measured by the metric called luminous intensity, measured in candela. Because the energy emitted by the lamp is spatially uniform, the light will spread out following an inverse square law and will become less dense and less bright as the distance increases. Also, because of the uniform spatial energy, a single value can be used to measure the luminous intensity, and a single value can be used to measure the reflected luminance from a flat surface which was originally emitted by a curved surface. Mathematically, the light can be modeled as a single, infinitely small point and the light source can be considered a point source.

Flat Surface Emitter

The invention of solid-state lighting, which uses a flat surface chip to generate light, dramatically changes the properties of the light that's emitted. The photons emitted by the chip randomly escape at different angles, but because of the flat geometry of the chip, some of the light rays will overlap. The centre of the chip is where the most overlap occurs, with the least amount of overlap occurring near the edges. There is almost no light emitted from behind the chip. These important differences are not considered with current metrics.

Figure 2 shows a flat surface as the source of the light. The overlapping light rays create spatially non-uniform (anisotropic) energy, as each point in space has a different amount of energy. The mathematical profile of light from a flat surface generally follows Lambert's Cosine Law, which describes the amount of energy at each point in space.[1]

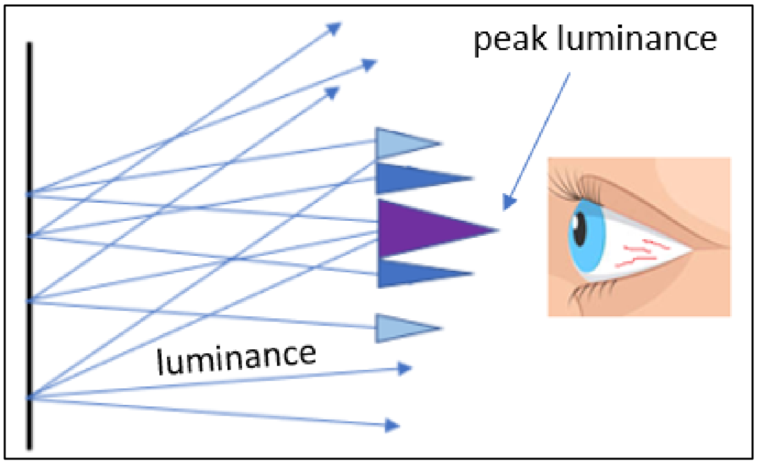


Figure 2

Because the light is emitted from a flat surface, the brightness is measured in nits (candela per square metre), and not luminous intensity as with a curved surface emitter.[2] This is why LED electronic displays advertise brightness with the number of nits. (LED headlights and LED streetlights should also specify their brightness in nits). A single value for luminance cannot be used for a flat surface emitter; however, we can state a "peak luminance" that quantifies the maximum luminance emitted by the chip. An LED light source cannot be modeled as an infinitely small mathematical point (point source) because the emitter geometry is flat, not curved, and the resulting radiation will always retain the Lambertian spatial energy shape, no matter how far away the viewer is from the source.

An LED emits visible radiation in a tight beam. Within that beam, the energy is spatially non-uniform. Even at a distance, for example many kilometres away, the light will remain dense, with little dispersion and little scattering, depending on environmental conditions. While light from a curved surface disperses following an inverse square law, flat surface sources focus the light into a narrow beam. For LEDs, the luminance metric is used to measure brightness at the source of the light in near field, and there will be a different luminance value for each point in space. Generally, these measured near-field luminance values will be unchanged at the destination, such as at the eye. For example, a peak luminance of 1,000,000 nits measured at the chip will still be 1,000,000 nits at an observer's eye 30 metres from the LED light source.

[1] http://www.softlights.org/wp-content/uploads/2022/03/Lambertian-2013.pdf
[2] https://ocw.snu.ac.kr/sites/default/files/NOTE/791.pdf

Comparison of Curved Surface and Flat Surface Emitter

A curved surface emitter such as a tungsten filament will emit essentially spatially uniform isotropic radiation as shown in (a) and (c) of Figure 3. A flat surface emitter such as an LED will emit spatially non-uniform anisotropic radiation, as shown in (b) and (d).

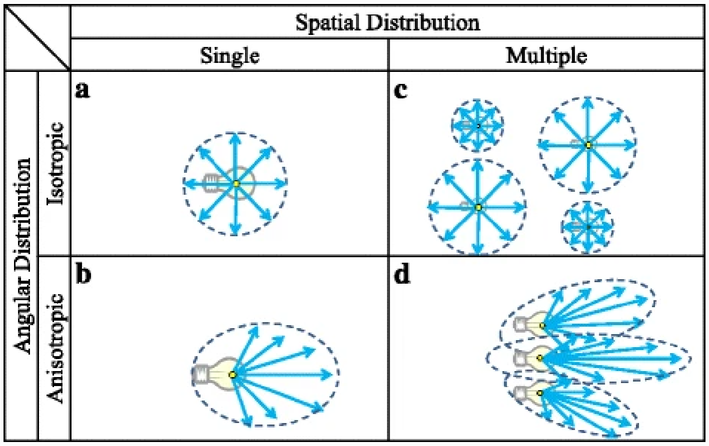


Figure 3 - Isotropic vs. Anisotropic[3]

Figure 4 shows a cross section of the radiation emitted from a light source as it lands on a surface. Isotropic radiation such as from a tungsten filament or gas-discharge light source will create a uniform distribution of light, whereas the anisotropic radiation emitted from a flat surface LED will create non-uniform light distribution, with much of the radiation concentrated in the centre. The precision needed to measure the distribution of LED radiation is on the femtometre or picometre scale.

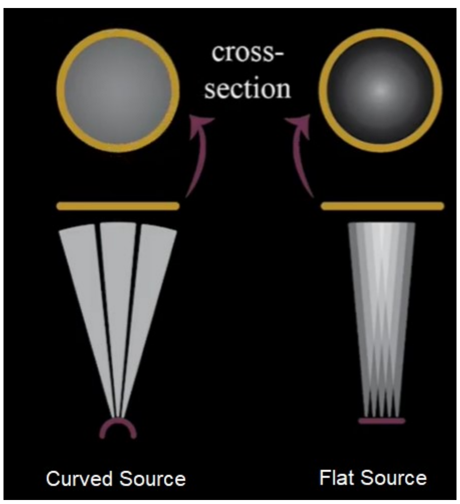


Figure 4 - Spatial Distribution Comparison

[3] https://ipsjcva.springeropen.com/articles/10.1186/s41074-016-0014-z

Summary

In summary, metrics previously used for curved surface emitters such as tungsten filament and gas-discharge lamps cannot be used for flat surface emitters. The brightness of a flat surface emitter is measured via peak luminance in nits (candela per square metre). LED visible radiation is spatially non-uniform.

November 14, 2022

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3. Is Street Lighting Damaging Our Health? - https://online.flippingbook.com/view/702884488/ - Cree Lighting acknowledges that LEDs emit non-uniform luminance.

4. Light Emitting Diodes, Chapter 16, Human Eye Sensitivity and Photometric Quantities - https://ocw.snu.ac.kr/sites/default/files/NOTE/791.pdf - States that point source brightness is measured with luminous intensity in candela, and surface source brightness is measured with luminance in nits (candela per square meter).

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6. Angular Distribution of the Averaged Luminous Intensity of Low Power LEDs Transfer Standards - http://www.softlights.org/wp-content/uploads/2022/03/Lambertian-2013.pdf - LEDs emit non-uniform energy in a Lambertian shape, sometimes off-centre.

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