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Microscopic characterization of function and structure within solid state lighting devices*

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Abstract

Microstructural investigations of solid state lighting devices are carried out by example of an LED filament. A workflow is presented combining X-ray computed tomography with light and electron microscopy. It allows a precise sample preparation which enables microscopic investigations of the inner structures within the device. Therefore the LED filament may still be electrically operated although a destructive preparation cannot be avoided. Optical functions and behavior are observed and correlated to material and structure on the microscale.

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Keywords: Solid state lighting; Filament LED; Correlative microscopy; Luminescence; Scanning electron microscopy; Computed tomography

1. Introduction

Solid State Lighting (SSL) is replacing other lighting technologies in most application fields. Especially the utilization of white Light Emitting Diodes (LED) increases continuously due to their advantages of high luminous efficacy, long lifetime and small size [1]. White LEDs for lighting applications usually consist of blue emitting

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semiconductor dies combined with at least one phosphor. This phosphor converts part of the narrow-band blue light into a broad- band yellow emission which results in white light with appropriate color rendering properties [2].

To obtain high luminous efficacies the optical materials as well as the semiconductor die have to be very efficient. Thermal effects should be minimized as they could lead to degradation or other aging artefacts shortening the lifetime of a LED. Furthermore, the materials should be highly stable over the lifetime and reproducible in high quality over long production periods to ensure lasting quality of the devices. Therefore, the performance of LEDs and SSL devices in general strongly depends on the materials used as well as their micro- and nanostructure.

Nowadays, LED filament light bulbs [3,4] are often the first choice if classic incandescent light bulbs have to be replaced in consumer luminaires. Next to energy saving the main advantages of these lamps are similar luminous intensity distributions and similar appearance due to the visible filament while shape, dimensions and electric sockets remain the same [5]. Compared to classic light bulbs, the incandescent filament is substituted by an LED filament and an electronic circuit is placed into the socket to drive this filament with a direct current. The LED filaments basically consist of a line of several single blue-emitting LED chips which are directly mounted on a stripe of transparent substrate, mostly glass or sapphire. The chips are bonded in series connection and the whole stripe is coated with phosphor particles for color conversion which are embedded in silicone serving as encapsulation [6]. The main challenges of the lamps are heat dissipation within the device and thermal stability of the materials used.

In the following sections a commercially available LED filament light bulb is characterized on the microscale. The investigated lamp has a standard E14 socket and emits a luminous flux of 230 lm with a color temperature of 2700 K spending 2 W electrical power when operated at 230 V / 50 Hz power supply according to the data sheet.

2. Electrical and optical characterization

The underlying principle for white light emission which mainly consists of blue light from the semiconductor and yellow light from the phosphor conversion can already be extracted from the emission spectrum of this device. Fig. 1 shows the spectrum (solid line) obtained under normal operating conditions. The narrow blue peak with its maximum at 449 nm wavelength and the broad yellow peak (λ_{max} = 608 nm) can clearly be observed and separated. From spectral data a correlated color temperature (CCT) of 2711 K is calculated. This value only refers to the color appearance being similar to a black body emission at this temperature (dotted line in Fig. 1), e.g. from an incandescent lamp. The difference in both spectra finally results in an inferior color rendering of the LED (measured color rendering index R_a = 82) compared to an incandescent lamp (R_a is per definition 100).

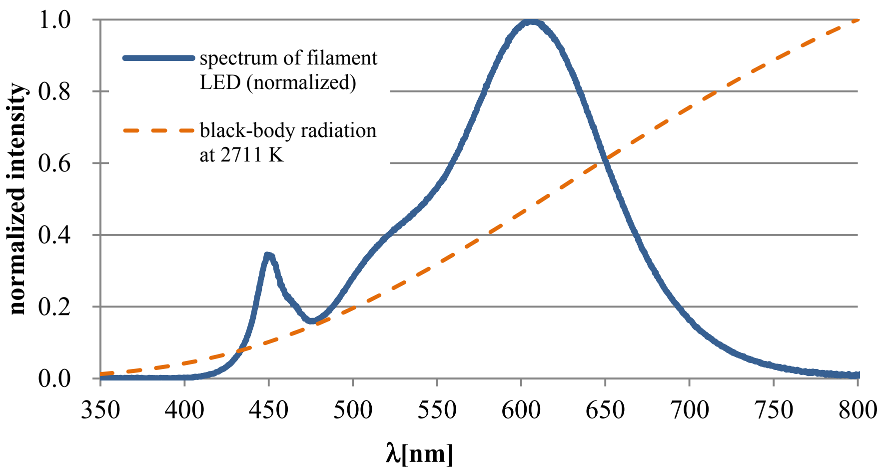

Fig. 1. Emission spectra of the filament LED (solid line) and a respective incandescent lamp (dotted line).