Light conversion and colour mixing with luminescent light guides

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Luminescent light guides on the basis of Dy^{3+}-doped lithium aluminoborate glass are presented. Optical simulations are performed to show the huge potential of these light guides with respect to colour mixing and luminance output.

1 Introduction

Continuous efficiency improvements of white light LEDs enable ever greater radiant power from ever smaller areas. As a result, the demands on the light converter used in phosphor-based LEDs with regard to temperature and radiation stability are increasing. This is a major challenge for the durability and colour stability of the LED / phosphor combination. Luminescent borate glass represents a promising alternative to phosphor-polymer composites.

2 Experimental Details

The luminescent light guides investigated are based on lithium aluminoborate (LiAlB) glass, which consists of B_2O_3 (99.98 % purity) as network former and Li_2O (99.5 % purity) as network modifier in a ratio of 2 to 1. To prevent devitrification and to increase the strength of the glass [1, 2], 10 % of the B_2O_3 is substituted by Al_2O_3 (99 % purity). For optical activation, the samples are doped with 0.5 mol% Dy_2O_3 (99.99 % purity), added at the expense of all other chemicals. Light guides of four different lengths are produced, namely 10.4 mm, 21.3 mm, 30.9 mm, and 47.2 mm (Figure 1).

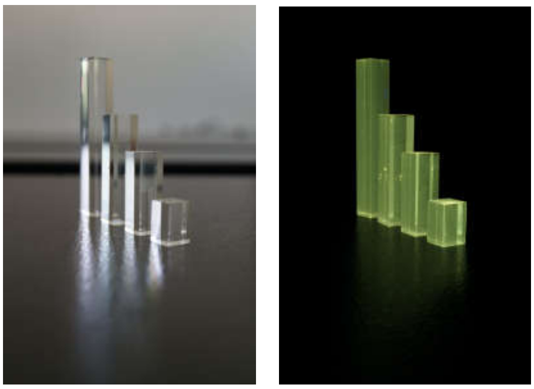

Fig. 1 *Dy^{3+}-doped LiAlB glass light guides under daylight conditions (left) and under ultraviolet excitation (right).*

Transmittance and reflectance measurements are carried out with a UV-Vis-NIR spectrophotometer (Agilent Technologies Cary 5000). Photoluminescence emission and quantum yield measurements are performed with an absolute photoluminescence quantum yield measurement system (Hamamatsu C9920-02G) coupled to an integrating sphere with a xenon lamp (150 W) for excitation and a photonic multichannel analyser (PMA-12) for detection. Photometric measurements are realized with a robot goniophotometer (opsira robogonio mrg-6), while luminous intensity data are recorded in the far field with a photometer in combination with a $V(\lambda)$ filter (opsira frc'3-f-l). For ray-tracing simulations, the software package LightTools (Synopsys, Inc.) is used.

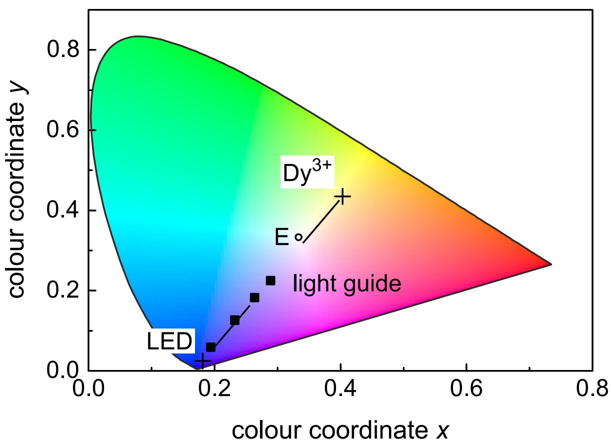

Fig. 2 *Colour coordinates for the different UV-LED / Dy^{3+}-doped glass combinations. The colour coordinate of the LED as well as that of the Dy^{3+} emission are indicated by crosses.*

3 Results and discussion

The two crosses in the CIE diagram (2° standard observer) as shown in Fig. 2 indicate the colour coordinate of the LED excitation (391 nm) used in the experiments as well as that of the Dy^{3+}-related emission. The connecting line between theses crosses corresponds to the positions of possible mixed colours. In the experiment, the 391-nm LED is coupled into the end face of the light guide, while the Dy^{3+} emission is recorded at the opposite front face. The four full squares in Fig. 2 mark the colour coordinates of the front face emission of the light guides in different lengths. As the length of the light guide increases, the colour coordinate shifts more and more to the point of equal energy (E).

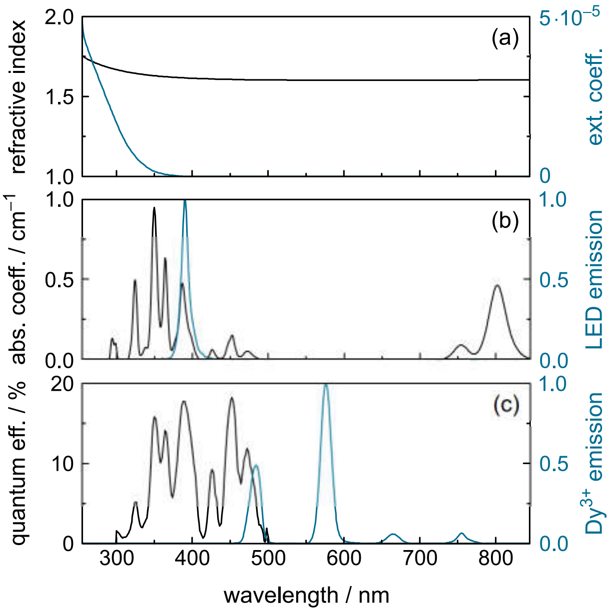

Fig. 3 *Input data for optical simulations: (a) refractive index and extinction coefficient of the glass, (b) absorption coefficient of 0.5 mol% Dy^{3+} and normalized LED emission, (c) quantum efficiency and normalized Dy^{3+} emission.*

For ray-tracing simulations, the optical parameters as well as the geometry of the light guides serve as input parameters. The luminescent glass is modelled as a combination of a matrix material (glass) and a luminescent dopant (Dy^{3+}) within. The optical parameters of the base glass, i.e., refractive index and extinction coefficient, are shown in Fig. 3(a), while Fig. 3(b) shows the Dy^{3+}-related absorption coefficient and the normalized LED emission used for excitation. The Dy^{3+} quantum efficiency as well as the Dy^{3+} emission are shown in Fig. 3(c).

Fig. 4 shows the simulated luminance emitted via the front face of the light guide (blue curve) in comparison with the input luminance of the LED (black curve). There is a significant increase in the front face luminance with increasing length of the light guide. The luminance is mainly due to the Dy^{3+} emission since the 391-nm excitation light is hardly perceived by the human eye. The observed raise is consistent to the absorption over length dependence. At a length of 100 mm, the luminance seems to saturate. The dimensions of the end and front face are 7.1 mm × 7.1 mm, the optical power of the 391-nm LED is set at 1 W.

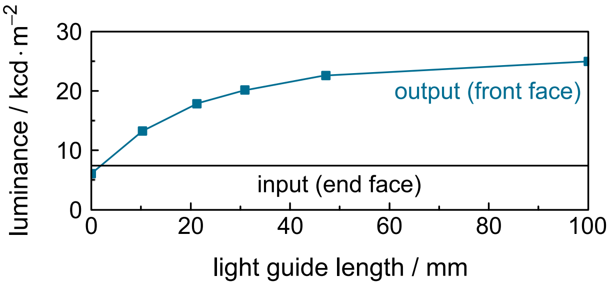

Fig. 4 *Luminance emitted via the front face of the luminescent light guide (blue curve) in comparison with the input luminance of the 391-nm LED (black curve).*

Furthermore, the far-field luminous intensity distribution is simulated and compared to the recorded experimental values (Fig. 5). With respect to shape and intensity, the simulation is in fair agreement with the experimental data. Shading effects from the sample holder cause slightly lower luminous intensity values in the experiment.

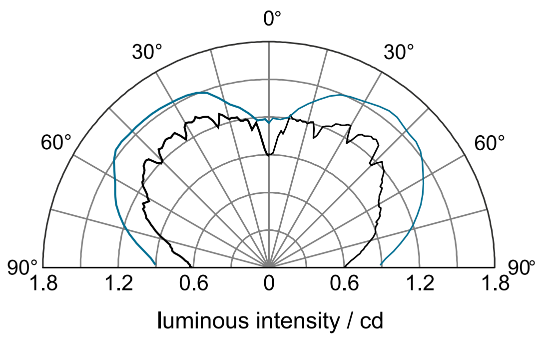

Fig. 5 *Simulated luminous intensity distribution (blue curve) in comparison with the experimental data (black). The length of the light guide amounts to 47.2 mm.*

4 Conclusion and outlook

The huge potential of luminescent light guides has been proven by optical simulations of Dy^{3+}-doped light guides in different length. The length of the light guide affects not only the colour mixing properties, but also the emitted luminance.

5 Acknowledgment

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