Simulation of a luminescent light guide

Franziska Steudel*, Juliane Steinbrück**, Stefan Schweizer*,**

*Fraunhofer Application Center for Inorganic Phosphors, Branch Lab of Fraunhofer Institute for Microstructure of Materials and Systems IMWS, Lübecker Ring 2, 59494 Soest, Germany

**Faculty of Electrical Engineering, South Westphalia University of Applied Sciences, Lübecker Ring 2, 59494 Soest, Germany

mailto: Franziska.Steudel@imws.fraunhofer.de

Optical simulations are performed on a luminescent light guide to understand the luminous intensity distribution of this system. The simulations are compared to the experimental results from a red-emitting light guide based on Eu^{3+}-activated borate glass.

1 Introduction

Increasing power densities of white-light-emitting diodes (LEDs) lead to increased requirements not only for the LED chip itself, but also for the light-converting phosphor on top. Here, luminescent borate glass represents an interesting alternative as phosphor material due to its high thermal and chemical stability. Ray-tracing simulations on light-converting light guides made from Eu^{3+}-doped borate glass reveal information on luminous intensity distribution as well as color distribution.

2 Experimental Details

The lithium borate glass is prepared using the base components boron oxide (B_2O_3) and lithium oxide (Li_2O) in a molar ratio of two to one. To strengthen and to prevent devitrification of the glass, 10 % of the B_2O_3 is substituted by aluminium oxide (Al_2O_3). For optical activation, the glass is additionally doped with the lanthanide ion Eu^{3+} by adding 1 mol% Eu_2O_3 to the starting mixture. The chemicals are weighted and then melted at 1000 °C in a platinum/gold crucible (Pt/Au 95/5) for 3 hours. After melting, the liquid is poured onto a pre-heated brass block at 400 °C, which is below the glass transition temperature of 459 °C [1]. The glass is kept at this temperature for 3 hours to eliminate residual mechanical and thermal stresses before allowing it to slowly cool to room temperature. The light guide has a square base of 7 mm × 7 mm and a length of 64 mm. The sample is polished from each side to optical quality.

Optical measurements are performed with an UV-Vis-NIR spectrometer (Agilent Technologies Cary 5000) and a quantum yields measurement system (Hamamatsu C9920-02G). Far-field measurements are performed with a robot goniophotometer system (opsira GmbH robogonio). A frc'3-f-l photometer is used to record the luminous intensity. The luminescent glasses are excited with a 469-nm LED (Cree XP-E2) operating at 400 mA and having an almost lambertian luminous intensity distribution. Optical simulations are performed with the software package LightTools® from Synopsys [2].

3 Results and discussion

For the simulations, the geometry and the position of all objects as well as the material parameters must be known. The luminescent glass is modelled as a combination of an undoped matrix material (glass) and a luminescent dopant (Eu^{3+}). The optical constants of the undoped glass, the absorption coefficient, quantum yield and emission spectrum of Eu^{3+} as well as the LED emission spectrum are shown in Fig. 1.

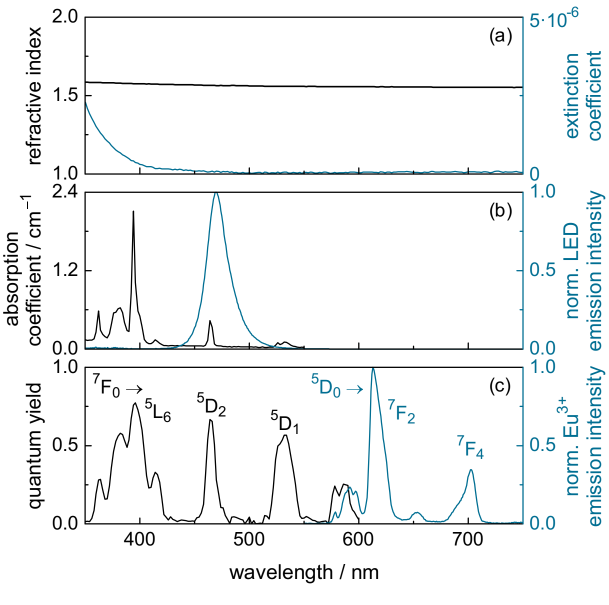

Fig. 1 *Input data for the optical simulations: (a) refractive index and extinction coefficient of the undoped glass, (b) absorption coefficient of 0.5 at.% Eu^{3+} and LED emission spectrum, and (c) quantum yield and emission spectrum of Eu^{3+}.*

The Eu^{3+}-activated borate glass light guide is excited with the 469-nm LED from the front face. The non-absorbed excitation light exits the light guide at its

DGaO-Proceedings 2019 – http://www.dgao-proceedings.de – ISSN: 1614-8436 – urn:nbn:de:0287-2019-P015-9
submitted: 15.Jul.2019 published: 02.Sep.2019

end face where it leads to a pattern as shown in Fig. 2. The optical activator Eu^{3+} emits isotropically its typical red light which exits the light guide within the angle of total internal reflection via the side faces (Fig. 2a). The observed pattern as well as the corresponding color distribution can be simulated accordingly (Fig. 2b). The large amount of blue light leaving the light guide via the end face indicates the low absorption coefficient of the lanthanide ion Eu^{3+}. A potential solution to this problem is to transform the glass into a glass ceramic by thermal processing [3].

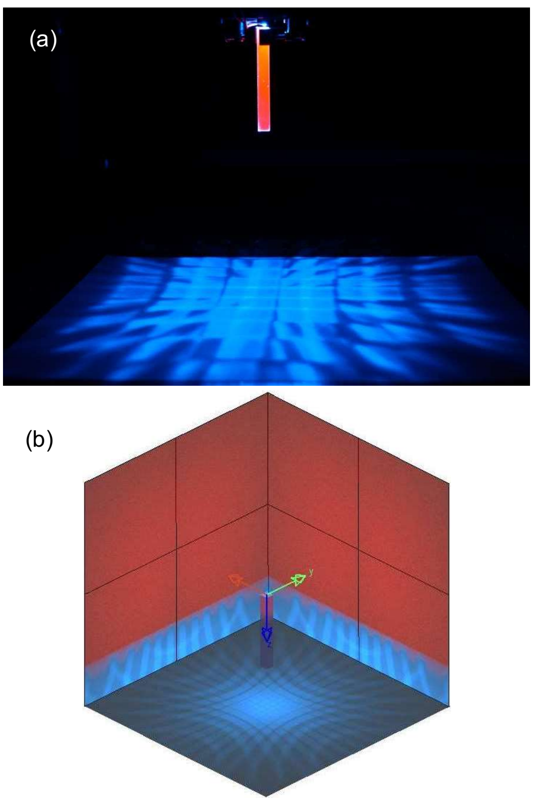

Fig. 2 *(a) Experimental setup for far-field measurements with the blue LED excitation from the top and (b) simulation of the color distribution of the luminescent light guide.*

Luminance measurements reveal a pattern within the light guide as shown in Fig. 3a. Simulations prove that the intensity pattern mainly results from the totally reflected blue excitation light. Fig. 3b shows the simulated color distribution at the side face within the light guide whereas Fig. 3c shows the simulated color distribution outside.

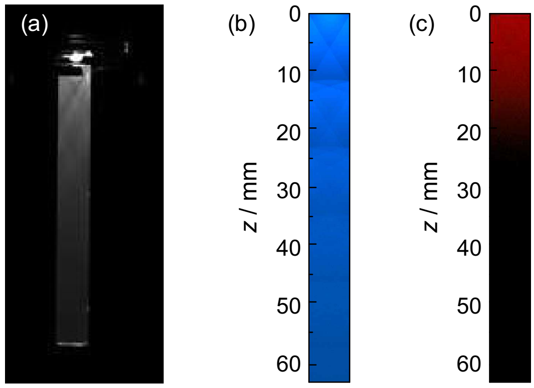

Fig. 3 *(a) Luminance measurement with the LED excitation from top and simulation of the color distribution (b) within and (c) outside the luminescent light guide.*

4 Conclusion

The optical simulations of a light-converting light guide are in a good agreement with the experimental data.

5 Acknowledgments

The authors wish to thank the “Ministerium für Innovation, Wissenschaft und Forschung des Landes Nordrhein-Westfalen” for its financial support to the Fraunhofer Application Center for Inorganic Phosphors in Soest. In addition, the authors would like to thank the German Federal Ministry for Education and Research (BMBF) for its support to the South Westphalia University of Applied Sciences within the FHprofUnt 2014 project “LED-Glas” (project no. 03FH056PX4).

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