Hybrid simulation of thermo-optical effects in laser-based white light sources

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Laser based remote phosphor light sources offer a very high brightness but are significantly influenced by the temperature of the phosphor conversion ceramic as well as self-absorption effects. This paper discusses both factors and suggests an approach to simulate this nonlinear material behavior.

1 Introduction

Laser-based white light sources, so-called remote phosphor systems, offer a significantly higher luminance than LEDs. Therefore the optical system, generating a specific light distribution may become much smaller using laser than using LEDs.

One application of this light sources are automotive headlamps since designers claim for slim contours while the ECE regulations demand specific light distributions. The solution: A light source with high luminous flux and small étendue.

2 Phosphors

The phosphor conversion element is often the weak point of remote phosphor systems. While semiconductor lasers can be focused very precisely on the phosphor layer, the limited thermal conductivity of ceramic phosphors leads to strong temperature gradients in the conversion element and therefore position-depending material properties, e.g.

- Conversion efficiency
- Stokes shift
- Thermal conductivity
- Excitation and emission spectrum
- Scattering
- Absorption

Due to the so called Thermal Quenching the conversion efficiency of phosphor materials is strongly temperature dependend. YAG:Ce has a relatively high quenching temperature, making it the most favourable phosphor for many applications. One important aspect is the self-absorption of this material. Since excitation and emission spectrum show a certain overlap, a part of the emitted (converted) light is re-absorbed by the phosphor (Fig. 1). This leads to a significant red-shift of the emitted light with increasing thickness of the conversion layer and its doping concentration (Fig. 2).

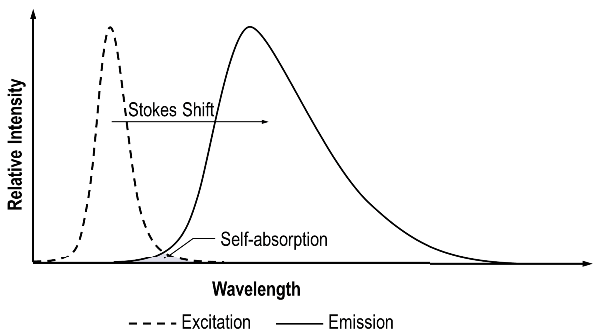

Fig. 1 *Excitation and emission spectrum of a phosphor (schematic).*

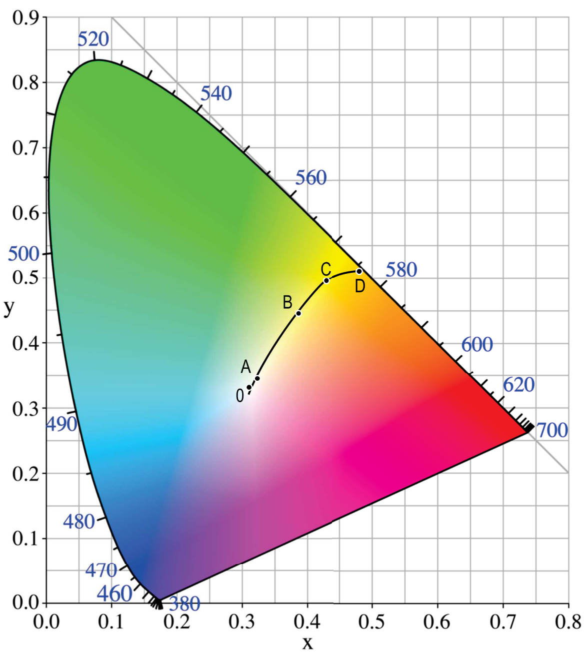

Fig. 2 *Color coordinates of YAG:Ce, excited at 450nm, different phosphor thicknesses and doping concentrations.*

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3 Hybrid optical simulation

Today's optical simulation tools typically describe phosphor materials as additional light sources, based on a data base (Fig. 3). Using ray tracing tools the exciting light as well as the converted light can be described. But the correlation between the temperature profile of the phosphor material and its emission characteristics can't be considered properly. Therefore this simulation strategy is inaccurate.

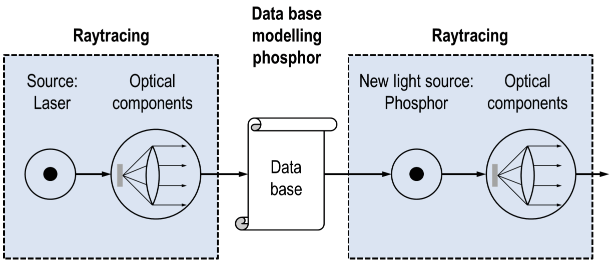

Fig. 3 *Conventional sequential simulation, ray tracing with data base modelling phosphor.*

Our idea is to set up a simulation environment based on the combination of ray tracing and thermomechanical simulation in order to model the correlation more accurately (Fig. 4). This allows the development of optical systems working at the thermal limits of the conversion layer and therefore offering a very small étendue without losing too much of the systems efficiency.

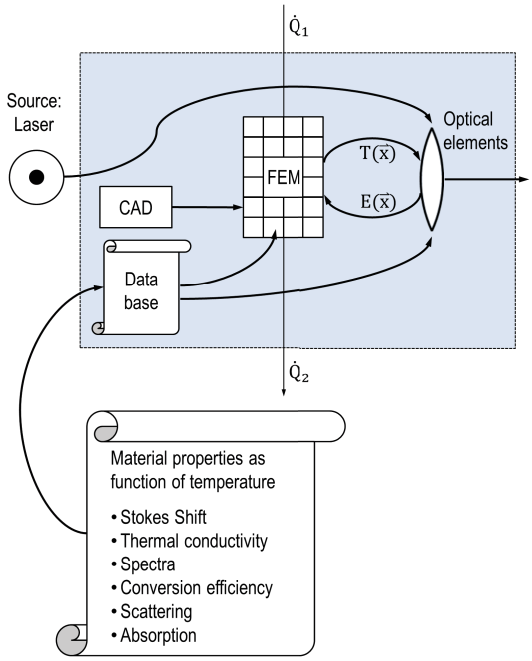

Fig. 4 *Hybrid simulation, coupling of ray tracing and thermomechanical simulation.*

4 Note

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