Multiphysics simulation strategy for the optimization of laser-excited remote phosphor systems

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A simulation strategy that couples the optical and thermal effects of laser-excited remote phosphor systems is proposed here. This coupling is essential for investigating the thermal limitations and deriving the optimization parameters of these systems as different underlying effects come into play.

1 Introduction

A new family of products is developed as lasers replace LEDs in the remote phosphor configuration. These laser-excited remote phosphor systems (LRPSs) exhibit advanced characteristics compared to conventional light sources or even other solid-state lighting solutions such as significantly higher luminance and much smaller étendue. Moreover, their smaller light-emitting surface and divergence can be utilized in the creation of sharp and exact light distributions. The downsizing of the final product and as a result the downscaling of the optics used can lead to a reduction of the resources required, while the physical separation of the optical pump source and phosphor allows better thermal management and design freedom.

Although these systems are already in use in commercial applications, the bottleneck in their performance is often considered to be the temperature dependence of the phosphor's emission characteristics: Over a certain temperature threshold, i. e. the thermal quenching temperature, the phosphor's emission efficiency drops to practically zero. Thermal quenching introduces thermal limitations to the lighting devices developed, while, conversely, an optical system operating on the thermal limit of the conversion layer exhibits optimal efficiency. As a result, in order to investigate these limitations and derive the optimization parameters of LRPSs, a simulation strategy has to be devised that couples the optical and thermal effects.

Retaining the basic structure of the ray tracing method for phosphor-converted white light sources, the temperature profile of the phosphor layer is calculated based on the transient heat equation. In each time step, heating that occurs due to the combined effect of Stokes shift and non-radiative losses as well as the system's thermal management mechanisms are considered. The quantum efficiency is recalculated based on the current temperature profile, while its temperature dependence is derived based on the material's radiative and non-radiative lifetimes.

2 Remote phosphor systems

LRPSs that are of interest in lighting applications basically consist of a blue laser diode (450-460 nm) and a conversion phosphor emitting in the yellow - green spectral range (most commonly YAG:Ce). The color impression is determined by the balance between these two spectral components.

Modeling a remote phosphor system is a highly complex and sophisticated problem, since the scattering of the exciting and converted photons, the absorption and re-emission properties of the phosphor as well as the interaction between the optical pump source, the conversion layer and its supporting mechanical structure have to be taken into account. This is achieved here by performing opto-thermal analysis on the phosphor and its supporting mechanical structure / heat sink, which can be regarded as a layered structure. For both static LRPSs set-ups: the reflective and transmissive, see Fig. 1, the appropriate number of layers is considered; in the reflective configuration there is an additional layer modeling the reflector.

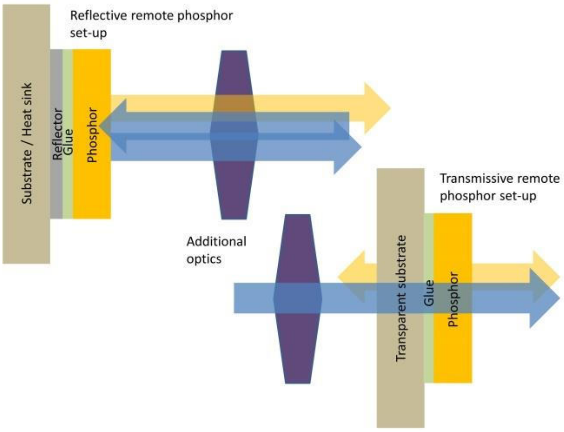

Fig. 1 *Remote phosphor system configurations*

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3 Opto-thermal simulation model

The opto-thermal simulation model presented here is based on an iterative procedure: an optical simulation is performed to calculate the volumetric heat source that is subsequently used in thermal analysis. The simulation termination criteria are that either the system reaches its steady-state or the quantum yield drops below the threshold for which white light is produced. In addition, for simulation purposes the phosphor layer is considered a bulk diffuser; its behavior is modeled by the bulk scattering properties (phase function, absorption and scattering coefficients). Other layers added that comprise the phosphor sample as a whole, e.g. substrate, may further scatter the converted light, though bulk scattering is not taken into account for those cases.

The methodology employed for the optical part is Monte Carlo ray tracing, while the thermal analysis is performed using the finite element method (FEM). A description of the optical phenomena and modeling techniques can be found in [1] and [2]. Here, the combined opto-thermal model flowchart is shown in Fig. 2.

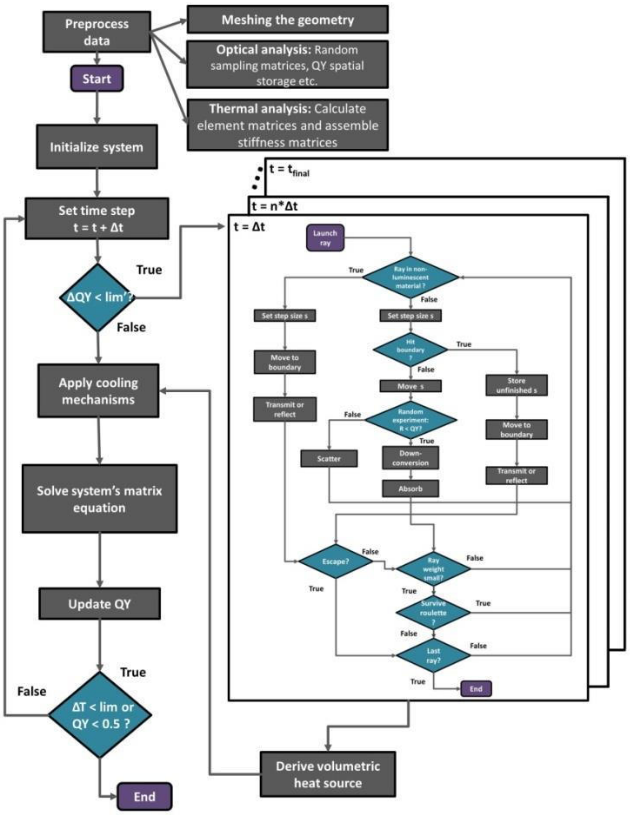

__Fig. 2__ Simulation model flowchart

4 Acknowledgement

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