Selecting Conversion Phosphors for White Light-Emitting Diodes Package by Generalized Reduced Gradient Method in Dispensing Application

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***Abstract*—The conversion-phosphor selection engine with chromaticity coordinates and additive color-mixing theory for light-emitting diodes is constructed. The parameters are linked by the generalized reduced gradient method for optimization. Finally, this model can be used in the LED dispensing process for 2700K and high color rendering index requirement.**

Key words: phosphor, color mixing, LED package.

I. INTRODUCTION

Because of constantly increasing energy prices, light-emitting diodes (LEDs) have been in focus due to their energy-saving potential. In the lighting market, the phosphor-cover LED (pc-LED) is the most promising type of package due to its low cost and long lifetime. The key components of the LED package for high efficiency are the blue chip and conversion phosphor. However, the phosphor selection is affected by the chromaticity coordinates, conversion efficiency, and cost [1]. There are many different types of conversion phosphors, so a fast selection method based on the phosphor database is required. The generalized reduced gradient (GRG) method is a generalization of the reduced gradient methods which allows nonlinear constraints and arbitrary boundaries to be imposed onto the variables during the calculation process [2, 3]. The GRG method can be used for LED-spectrum calculation or LED-package application [4–7]. In this study, the optimization engine to select the most suitable conversion phosphor efficiently from expandable database after choosing a specific blue LED and color-mixing target for the pc-LED package on the basis of the GRG method is discussed in the following.

II. CONSTRUCTION OF PHOSPHOR SELECTING MODEL

The overall phosphor-selection model constructing process is shown in Fig. 1. At the beginning, the chromaticity coordinates of several yttrium aluminum garnet (YAG)-based conversion phosphors are imported into the expandable database. The characteristics of the phosphor should be based on measurement results or data sheets. Then, to construct the optimized phosphor-selection engine, the next step is to choose the shortest distance between color-mixing target and the line between the blue chip and the individual phosphor color coordinates. However, the phosphor concentration will limit the position of chromaticity coordinates. Therefore, the information of the chromaticity coordinates in dependence of the concentration should be included in the model. Then, if a single phosphor cannot satisfy the color temperature or target chromaticity coordinates, a further phosphor will be considered. Finally, for the color rendering index (CRI) and efficiency requirements, an additional red LED was considered rather than a red phosphor.

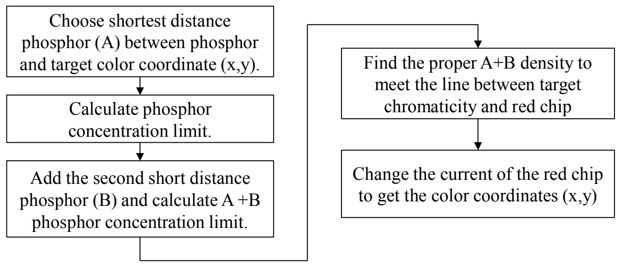

Fig. 1. Flow chart of the phosphor-selection model construction

As shown in Fig. 2, the target color temperature on the black-body curve is selected first (white point) according to the ANSI standard. And the color coordinate of the blue chip used in the package process (blue point) is defined. The additive color-mixing theory is also built in the model and linked with the GRG method. After the calculation, the best-suited phosphor is selected and recommended from the database. Moreover, the optimization engine can show the coordinates of best color-mixing point (pink point). However, the phosphor concentration will also limit the chromaticity coordinates mixing result. Therefore, by input the phosphor concentration information, including CIE x,y, the detailed recipe of pc-LED is provided ideally. In this case, for the 2700K target color temperature, the chromaticity coordinates will be saturated at high phosphor concentration, as shown in Fig. 3. Further boundary conditions are needed for the optimization engine.

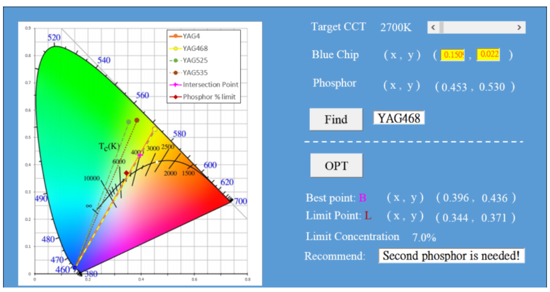

Fig. 2. Interface of the phosphor-selection engine.

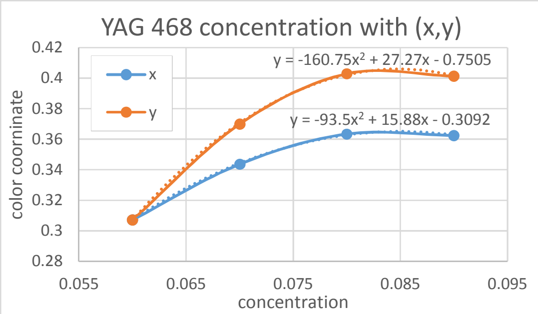

Fig. 3. Saturation of the color coordinate in dependence of the concentration of phosphor.

III. Adding Boundary Conditions to the Model

In Fig. 4, the color coordinates will achieve saturation at high phosphor concentration in the encapsulation material (red triangles). Therefore, the second-nearest phosphor (YAG535) was included to fine-tune the color coordinates. For the high CRI and efficiency requirements, an additional red LED was considered here. Then, the best color mixing point (green triangles) by YAG468 and YAG535 will be on the connecting line between red chip (red point) and target coordinates (white point). Finally, the target 2700K pc-LED with color coordinates (x, y) on the black-body curve would be achieved by this procedure. A prototype of the high-CRI dispensing pc-LED with red chip was realized, characterized by 93 CRI, 2765K, 782lm, and 97lm/W at 30mA. The prototype pc-LED and its spectrum are shown in Fig. 5.

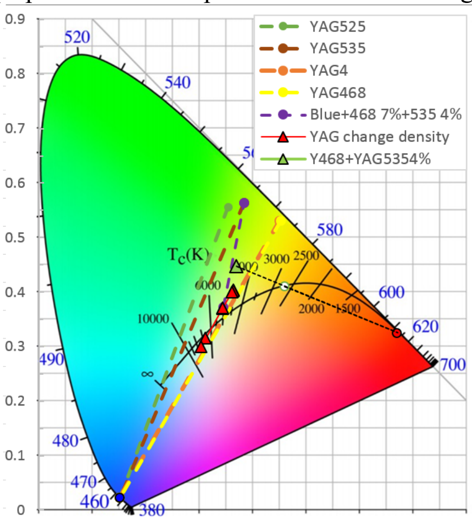

Fig. 4. The application of the optimization engine for 2700 K high CRI requirement with dispensing process.

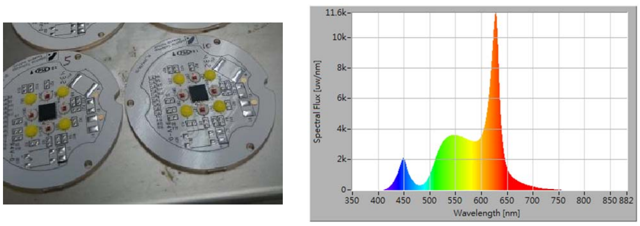

Fig. 5. The prototype dispensing LED (left) and its 2700K spectrum (right).

IV. Conclusions

In this study, the phosphor selecting optimization engine is proposed and calculated with generalized reduced gradient method for the LED dispensing process. After input the information of phosphor, including the chromaticity coordinates and concentration limit, the recommend conversion phosphors can be given during the optimization engine. Therefore, the phosphor recipe of PC-LED can be predicted before LED dispensing process in the future.

Acknowledgment

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