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硕　士　学　位　论　文

LED 荧光粉的发光性质分析和测试

Luminous Property Analyses and Testings of the LED Phosphor

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摘　要

在 LED (Light Emitting Diode) 芯片上涂敷荧光粉是目前实现 LED 白光照明的主要途径，而 LED 荧光粉发光性能的优劣直接影响白光 LED 发光特性，因此如何准确评价荧光粉发光、深入了解其发光特点是研究 LED 产品发光特性必须解决的核心问题。荧光粉在普通照明中应用的关键问题是光效、色度特性和热效应等。通过改变荧光粉粉层的粒度、厚度、形状、位置等参数，可以调节白光 LED 光效、颜色参数和空间光强分布。本文对荧光粉的各种发光特性展开研究，着重开展了对白光 LED 传统荧光粉封装方式和远程荧光粉封装方式的光学特性分析，研究内容包括以下几个方面：

1. 阐述了白光 LED 荧光粉的分类、发展历史、发光机理以及其特点和应用，介绍了荧光粉的几种传统测量方法、发光性能的评价机制。

2. 提出了一种基于积分球的蓝光 LED 激发荧光粉的性能测试系统及方法，能够反映荧光粉在实际工作条件下的发光性质，准确测量荧光粉的发光性能，避免传统测量的各种弊端。这种测量方法可靠，操作简单，误差较小，并且可以得到不同驱动电流下的荧光粉发光性能以及光谱功率分布。研究表明，该测量系统和分析方法可以很好地表征 LED 荧光粉的发光特性，通过电流调节，荧光粉可以和 LED 芯片达到较佳输出组合。同时，系统具有良好的扩展性能，通过灵活更换 LED 激发光源，易于实现紫外激发的 RGB 荧光粉等不同荧光粉对不同激发光源的要求。

3. 以传统白光 LED 和远程荧光粉白光 LED 作为研究对象，对其发光效能、量子效率、光转换效率、相关色温、光强分布等参数进行了表征。利用积分球、光谱测试仪、光强空间分布测试仪等多种分析测试手段，调节电流和温度等外界条件，研究了传统荧光粉涂覆方式和远程荧光粉涂覆方式对白光 LED 发光性能产生的影响，探讨了不同封

装方式的优缺点。通过传统白光 LED 和远程荧光粉白光 LED 的各项发光性能对比，发现随热沉温度和电流的上升，远程荧光粉白光 LED 的量子效率、光转换效率以及相关色温在相同实验条件下的变化幅度比传统白光 LED 更小，Y/B 比 (Yellow /Blue Ratio) 空间分布均匀性良好。对用不同激发光源去激发球冠状远程荧光粉后的光强分布观察结果表明，光源对光强分布影响不大，荧光粉的形状对光强空间分布有调整作用，因此可以通过设计不同的荧光粉形状来得到理想的光斑形状。

4. 研究了高色温和低色温两种球冠状远程荧光粉白光LED在不同电流、不同热沉温度下的发光性能差异。荧光粉的色温对整个白光LED系统的发光效率影响较大。实验结果表明：在大电流下，LED有源层内由于量子限制斯塔克效应使其峰值波长向短波方向移动，偏离了高色温荧光粉的最佳激发波长，更加接近低色温荧光粉的最佳激发波长，因此在大电流下，高色温荧光粉发光效率降低，低色温荧光粉发光效率升高。高色温LED的相关色温（CCT）随电流增加呈上升趋势，低色温LED的相关色温随电流增加呈下降趋势，与它们的量子效率变化引起的色坐标漂移有很大关系。两种LED量子效率和发光效能随热沉温度的升高均呈略微增大的趋势；其中，高色温LED的量子效率和发光效能随电流的增大而减小，而低色温LED的量子效率和发光效能则随电流的增大而升高。高色温LED发光性质较低色温LED好，但色特性的稳定程度不如低色温LED。

5. 提出了一种新型远程荧光粉封装白光 LED 系统，本文设计反光杯结构，采用荧光粉片远离蓝光芯片的封装结构并制备白光 LED，利用光学测试和光学仿真结合的方法将这种新型远程荧光粉封装白光 LED 系统和传统的远程荧光粉白光 LED 的发光效果进行对比，发现采用新型远程荧光粉白光 LED 系统可以极大地提高整个 LED 系统的发光效能，并有效降低了系统的 CCT，产生较高的 CCT 空间分布均匀性。本文详细阐述了两种不同白光 LED 系统的发光机理，解释了利用新型系统之后发光效能升高的原因。实验证明新型远程荧光粉白光 LED 系统这种封装方式具有更多的优点和更高的实用价值。

关键词：白光 LED；荧光粉；量子效率；光转换效率；发光效能

Abstract

Coating the LED chips with phosphor constitutes the major method to realize white LED lighting. The performance of LED phosphor directly determines the luminous property of WLED (white-light LED). Therefore, it is the core issue to analyze and evaluate performances of phosphors accurately and excavate lighting properties of those phosphors in depth. In practical daily lightings, the luminous efficacy, chromaticity and thermal effect etc. are of major concerns. The luminous efficacy, chromaticity and spatial light-intensity distribution of WLED can be altered by varying the particle size, thickness, shape and positions among others. In this dissertation, systematic researches concentrating on lighting properties of various phosphors have been carried out, emphasizing on optical-property analyses of conventional phosphor packaged LED and remote phosphor packaged LED. This dissertation comprises of several parts as follows:

a) Elucidations of the phosphor classification, development history, lighting mechanism, characterizations, applications, traditional measurement methods, and lighting performance evaluation of WLED.

b) Proposal of an integrating sphere based performance testing system and method for blue-light LED stimulating phosphors. The proposed method is capable of reflecting the phosphor lighting property under practical functioning circumstances and measuring the phosphor lighting performance accurately, freeing from various shortcomings of traditional measurement methods. This proposed method characterizes higher reliabilities, easier implementations and minor errors. Moreover, the lighting performance and spectral power distribution of phosphor under different driving currents can be obtained. Results demonstrate the feasibility of the proposed measurement system and analytic method in characterizing phosphor lighting performances. Optimal combinations of phosphor and LED chips can be achieved by adjusting currents. Additionally, the system is designed with excellent expansibility, which satisfies different demands of phosphors, i.e. the ultraviolet stimulating

oriented RGB phosphor, via fitting different LED stimulating sources.

c) Characterizations of the luminous efficacy, quantum efficiency, light conversion efficiency, correlated color temperature (CCT) and light intensity distribution of conventional WLED and remote phosphor WLED. The integrating sphere, spectrometer and light-intensity distribution detector etc. are utilized in the investigations of the influences brought by different packages on WLED performances under different currents and temperatures. Advantages and disadvantages of diverse packages are also discussed. From the experimental results, it can be drawn that the quantum efficiency, light conversion efficiency and CCT of remote phosphor WLED vary slower than those of the traditional WLED with the ascending currents and temperatures under same experimental conditions. Moreover, remote phosphor WLED possesses better Y/B ratio spatial distribution homogeneities. From observations of light-intensity distributions resulting from different stimulating sources, it can be concluded that stimulating sources are irrelevant to light-intensity distributions, and phosphor shapes may adjust the light-intensity distributions. Therefore, phosphor shapes can be specifically designed for expected light spot patterns.

d) Researches focusing on the light performance differences of both high and low CCT crown-shaped remote phosphor WLED under diverse currents and temperatures. The CCT differences greatly influence the luminous efficacy of the whole WLED. Experimental results suggest: the peak wavelengths slide towards the shorter-wavelength direction in the spectrum under large currents due to the quantum confinement stark effect in the LED active layer, departing away from the optimal stimulating wavelength of high CCT phosphors and approaching that of low CCT phosphors. The luminous efficacy of high CCT phosphor thus decreases, while that of low CCT phosphor increases. The behavior of CCT of those two distinct phosphor conveys contrary trends. The luminous efficacy and CCT variations of different phosphors is strongly related to the chromatic coordination drift caused by quantum efficiency variations. The quantum efficiency and luminous efficacy of both high and low CCT LED slightly increase with the ascending heat-sink temperature. Regarding high CCT LED, the quantum efficacy and luminous efficacy decrease with the ascending currents,

being contrary to the case of low CCT LED. The high CCT LED has better performances in lighting properties but less chroma-characterization stabilities than the low CCT LED.

e) Details of a newly-designed remote phosphor packaged LED system. The package, within which the phosphor slice isolates from the blue-light LED chip, is designed along with a reflector. The lighting performances of this and traditional remote phosphor packaged LED system are compared. The comparison indicates that the proposed system is capable of enhancing the luminous performance of the whole LED system, reducing the systematic CCT, and producing high CCT spatial distribution homogeneities. Lighting mechanisms of those distinct systems are analyzed in detail to explain the essence of luminous performance improvements with the proposed system. Advantages and application values over traditional remote phosphor packaged LED systems are sufficiently proven by experiments.

Keywords: white-light LED; phosphor; quantum efficiency; light conversion efficiency; luminous efficacy

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