A complementary study to "Toward scatter-free phosphors in white phosphor-converted light-emitting diodes:" comment

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Abstract: In a recent paper, Park et al. [Opt. Express 20(9), 10218 (2012)] demonstrated that large micro-size cube phosphors are an outstanding potential candidate for scatter-free phosphors in white phosphor-converted light-emitting diodes (pc-LEDs). They found that large micro-size cube phosphors can lead to higher luminous efficiency (LE), higher packaging efficiency (PE), and reduced influences of ambient temperature and applied current. In this comment, we further discussed the large micro-size phosphors on the angular color uniformity (ACU). It is found that when the phosphor particle size increases from 30 μm to 100 μm, the ACU decreases from 0.91 to 0.86.

OCIS codes: (230.3670) Light-emitting diodes; (290.0290) Scattering; (290.4020) Mie theory.

References and links

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Recently, Park et al. [1] compared the optical properties of phosphor-converted light-emitting diodes (pc-LEDs) with large micro-size cube phosphors (~100 μm) and commercial micro-size powder phosphors. They demonstrated that large micro-size cube phosphor was an outstanding potential candidate for scatter-free phosphors in white pc-LEDs for the luminous efficiency (LE) and packaging efficiency (PE) were improved respectively by 17% and 34% at 4300 K under 300 mA. They also found that the influences of ambient temperature and applied current on the optical properties were reduced. Actually, besides the LE and PE, the angular color uniformity (ACU) is also one of the significant properties of high white light quality [2,3]. In this comment, we mainly discuss the effect of phosphor particle size on ACU, and especially inspect the ACU characteristics of the large micro-size phosphors with

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considering the effects of phosphor concentration. We found that large phosphor particle size would deteriorate the ACU and it should be deliberative when using the large micro-size phosphors in the packaging.

For comparison, we built a same model with the experimental blue GaN LED package in ref [1]. The large micro-size phosphors were embedded in silicone binder resin and screen-printed on glass substrate to a thickness of 200 μm. The size-dependent optical constants, including the scattering and absorption coefficients for both the blue light and yellow light, which vary with the phosphor concentration, were calculated based on the Mie-Lorenz theory [4,5]. According to ref [1], the phosphor particle size in this comment ranges from 30 μm to 100 μm and phosphor concentration varies from 10 to 50% (wt.). For modeling the phosphor-conversion process, two wavelengths were simulated: one for representing the blue LED emission (465 nm), and the other one for representing the phosphor-converted yellow emission (557 nm). The yellow emission was traced immediately after the ray-tracing process of blue excitation was finished. More simulation details can be referred to our previous studies [6–9]. Both the blue light and yellow light irradiance distribution were recorded by a large detector. Based on the recorded data, the corresponding chromaticity coordinates (CIE1931 XYZ) and the correlated color temperature (CCT) were obtained.

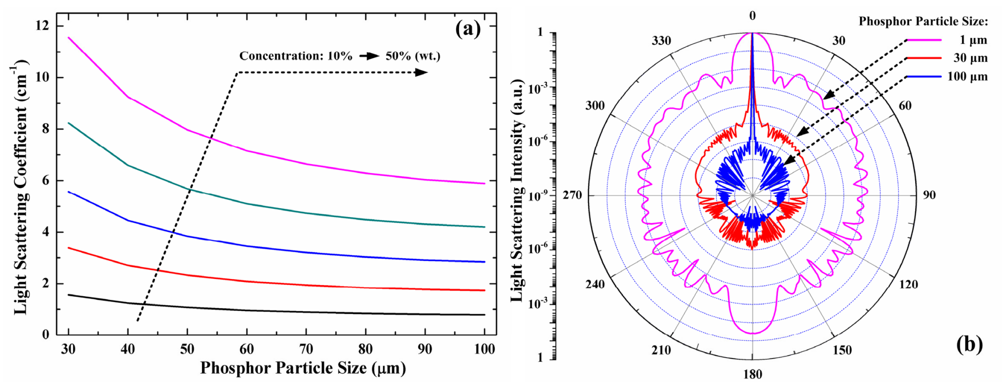

Fig. 1. (a) Variation of light scattering coefficients with phosphor particle sizes and phosphor concentrations. (b) Dependence of light scattering intensity on single particle with sizes of 1μm, 30μm, and 100μm.

The calculated scattering coefficients were plotted in Fig. 1(a). It is seen that with the increase of phosphor particle size, the scattering coefficients witness a trend of decrease and the increase of phosphor concentration enhances the scattering coefficients. The dependences of light scattering intensity of single phosphor particle on different sizes are shown in Fig. 1(b), in which the Angle 0 denotes the forward scattering, and the Angle 180 denotes the backscattering. It is seen that when the particle size increases from 30 μm to 100 μm, the forward scattering intensity is enhanced greatly. For comparison, the light scattering intensity for particle of 1 μm was also calculated and shown. It is seen that for smaller particles, the scattering intensity tends to be isotropic; for larger particles, the scattering intensity tends to be anisotropic with a strong forward maximum intensity.

The simulated CCT variations with different phosphor particle sizes in the whole radiation angle are pictured in Fig. 2(a). The phosphor concentration in the simulations was 50% (wt.). The simulated CCTs are close to the experimental results in ref [1]. On the CCT curve, there exists an obvious peak in the center region and a big drop in the edge region, which corresponds to the formation of "yellow ring" in the edge region of pc-LEDs [6,8]. The increase of phosphor particle size leads to sharper CCT peak in the center region. The ACU is defined as the ratio of the minimum CCT to the maximum CCT [6–8]. In the inset of Fig. 2(a), when the phosphor particle size increases from 30 μm to 100 μm, the ACU decreases from 0.91 to 0.86 by 5.8%. The increase of phosphor particle size contributes to the decrease

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of ACU, which implies that the large phosphor particle deteriorates the ACU of pc-LEDs. The comparisons of ACU for particle sizes of 30 μm and 100 μm with changing phosphor concentration are plotted in Fig. 2(b). It is seen that when the phosphor concentration changes from 10 to 50%, the ACU for particle of 30 μm increases from 0.85 to 0.91 by 7.1%; while the ACU for particle of 100 μm increases from 0.83 to 0.86 by 3.6%. The increase of phosphor concentration could enhance the ACU, and seems to make bigger difference on smaller particles. For large particles, the effect of phosphor concentration on ACU is weakened, and the causes may be attributed to the strong anisotropy of light scattering intensity of large particle size.

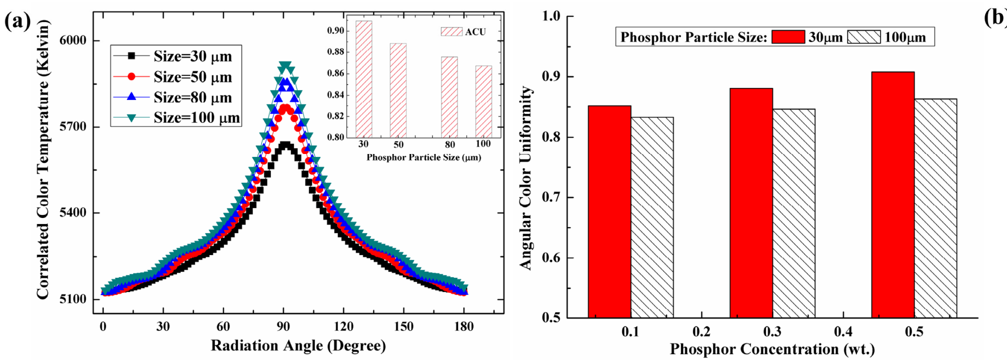

Fig. 2. (a) Variations of CCT and ACU with changing the phosphor particle size. (b) ACU variation with changing phosphor concentration for phosphor particle sizes of 30 μm and 100 μm.

In conclusion, although the large micro-size phosphors can enhance the LE and PE to some extent as presented in ref [1], they will deteriorate the ACU. And the enhancement of ACU by increasing the phosphor concentration is limited for large particles. Therefore, it should be deliberative when applying the large micro-size phosphors. For those applications where the ACU is not so important, the large micro-size phosphors can be used according to ref [1]; for those applications where the ACU is an important property, the large micro-size phosphors may not be used.

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