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A novel phosphor structure for improving the luminous flux of white LEDs

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Article Info

ABSTRACT

This section focuses on the color uniformity and luminous production of multi-chip white-emitted LED lighting systems (MCW-LEDs) in improving illuminated performance. To accomplish the desired outcome, $CaO:Sb^{3+}$ must be mixed with their phosphor compounding, which has been shown to have a massive impact on illuminating effectiveness. There is also evidence that the increasing of yellowish-green-emitted phosphorus $CaO:Sb^{3+}$ concentration supports color homogeneity as well as luminescent effectiveness enhancements in MCW-LEDs featuring a 8500 K correlating colour temperature (CCT). Meanwhile, that rise in $CaO:Sb^{3+}$ concentration leads to the gradually deteriorating color quality scale. Thus, if appropriate concentration and particle size of $CaO:Sb^{3+}$ phosphor are determined, it is not hard to obtain such an excellent presentation in color uniformity, color quality scale and luminescence of MCW-LEDs.
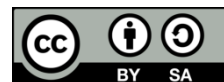
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1. INTRODUCTION

Because of concerns about energy savings and environmental problems, solid-state lumination (SSL) gadgets have widely substituted conventional illuminating supplies [1], [2]. Furthermore, SSL gadget has benefits such as high shock and vibration resistance and outstanding extended duration. The light-emitted diodes (LED) is a type of SSL gadget made of artificial semiconductors including gallium nitride (GaN). Lately, because of the good conversion effectiveness and simplicity of manufacturing of the relevant gadget, combining blue-colored LED and yellow-emitted phosphorus emerged as one among the potential strategies for obtaining the white light generation using LED [3]-[5]. This type of LED is known as a phosphorus-conversion LED (pc-LED). Some techniques, such as phosphor-containing slurry, phosphorus-contacting LED dies, distant phosphorus, were utilized to create a pcLED [6], [7]. Between them, it has been proved that using a distant phosphor layer is the most favourable method for producing a pc-LED with elevated illuminated effectiveness as well as reduced temperature accumulation [8], [9]. In this LED design layout, on the other hand, heterogeneous excitement occurred frequently as a result of the blue-emitted photon' optic trail. As a result, a yellow ring can be seen around the perimeter of the light projection [10]. This reduces the color homogeneity of the relevant pcLED.

A phosphorus-layer covered pattern-sapphires surface (PSS) is employed in the study to improve the illumination dispersion from LEDs, hence increasing their correlating chromatic temperatures (CCT)

homogeneity. Because of the greater possibility of light escaping from LED then through the PSS [11], the latter can guarantee a rise in LED illuminating-collecting effectiveness. Furthermore, PSS is primarily used as a two-dimention grating diffracting an incident optical beam to a wider beam. In our advancement of the distant-phosphor-layer packaging design, we select the PSS that got a phosphorus coating sprayed over the opposing site as an important element. Spraying is an effective method for producing a uniformly thick layer, which advantages large-scale production [12], [13]. The benefits includes better consistency as well as low price [14]. The pc-LED CCT homogeneity using a distant phosphorus film predicated on a PSS is markedly increased over that of a pcLED using a distant phosphor layer relying on a planar sapphire layer.

2.　COMPOSITITION AND MODELING
2.1.　The composition of the yellowish-green $CaO:Sb^{3+}$ phosphorus

　　　　Before creating distant phosphorus configurations, phosphor $CaO:Sb^{3+}$ must be prepared using the chemical composition with the specific mole percent and weight of each ingrendients mentioned in the Table 1. In order to create $CaO:Sb^{3+}$, a process must includes steps of mixing, drying, firing, pulverizing. Initially, $CaCO_3$, Sb_2O_3 and $NaHCO_3$ need to be combined together by slurrying in the water [15], [16]. Next, the ingredients will be dried in the condition of air and then powdered. The mixture is then fired in NO for 1 hour in sealed quartz pipes at $1200^{\circ}C$. The outcome now needs to powderized again. After all, store the product in a well-closed container and keep it dry. The product now become a complete $CaO:Sb^{3+}$ phosphorus emitting yellow-green colored output with the highest 2.30 eV emission [17], [18].

Table 1. Ingredients of $CaO:Sb^{3+}$ phosphor

Materials	By mole (%)	By grams
$CaCO_3$	100	100
Sb_2O_3	0.1 (of Sb)	0.145
$NaHCO_3$	1	0.840

2.2. Structure of MCW-LEDs

　　　　The genuine MCW-LEDs phosphorus coatin is replicated using a flattened silicon sheet. This simulation procedure is performed over two distinct periods of time: 1) the structural configurations, MCW-LED lights' optic characteristics ought to be established, 2) the phosphorus compound optic effects are then strictly supervised via the variation of $CaO:Sb^{3+}$ concentration. Comprehending the effect which $YAG:Ce^{3+}$ and $CaO:Sb^{3+}$ phosphorus compounding had upon the MCW-LED lights efficiency had made some comparative analyses. Three different phosphor packaging designs of WLEDs with 8500 K CCT, including conformal phosphorus, the in-cup phosphorus, and the regional phosphorus configurations, are demonstrated in Figures 1(a)-(d) [19]. Besides, as Figures 1(a) and (b), the physical model and the specifications of a real MCW-LED lamp fabricated with conformal phosphor coating and a mean CCT of 8500 K, respectively. Also it denotes the modeling of a MCW-LED without $CaO:Sb^{3+}$ phosphor particles.

　　　　The details of each component in a simulated LED model can be presented as follows. The reflectors feature measurements in base floor, height, and top layer of 8, 2.07, and 9.85 mm, accordingly. The 0.08 mm thick conformal phosphorus compounds, encompasses chips of nine. Every chip of LED has a 1.14 mm square base area and a 0.15 mm height and is connected to the chamber of the reflector. Additionally, the luminous power and the peak wavelength in every LED chip are 1.16 W and 453 nm, respectively. All the phosphor configurations of LEDs use Mie-theory to assess the scattering of phosphor particles automatically. The real parameter of the spherical phosphor grains in this study is 14.5 μm, which is also applied for all phosphor particles in the simulation process. Besides, the phosphor compounding mainly consists of $CaO:Sb^{3+}$ particles, $YAG:Ce^{3+}$ ions, and silicon adhesive. The reflection coefficients in $CaO:Sb^{3+}$ is 1.85, while that in $YAG:Ce^{3+}$ is 1.83, 1.52 in silicone glue. The emitting spectrum of a phosphorus compoundings might be obtained when the phosphorus's refracting rate and ion diameter have been measured.

　　　　Figure 2 depicts the emitting spectrum in three phosphorus configurations of LED after adding $CaO:Sb^{3+}$ phosphors. In particular, Figure 2(a) shows changes in emitting spectrum of the CPG with $CaO:Sb^{3+}$ concentrations ranging from 0% to 24%. While Figure 2(b) is illustrating IPG's emission spectra featuring the $CaO:Sb^{3+}$ concentration range of 0% wt. -1.4% wt. Then Figure 2(c) demonstrates the emitting spectrum in the RPG when $CaO:Sb^{3+}$ phosphor layer is over the yellow-emitted YAG:Ce, given that $CaO:Sb^{3+}$ phosphor film concentration varies from 0% wt. to 20% wt. As can be seen from Figure 2, the increase in $CaO:Sb^{3+}$ concentration probably boosts the emission spectra of all the LED structures, which implies that adding $CaO:Sb^{3+}$ to the phosphor compound can enhance the MCW-LEDs lumen performance.
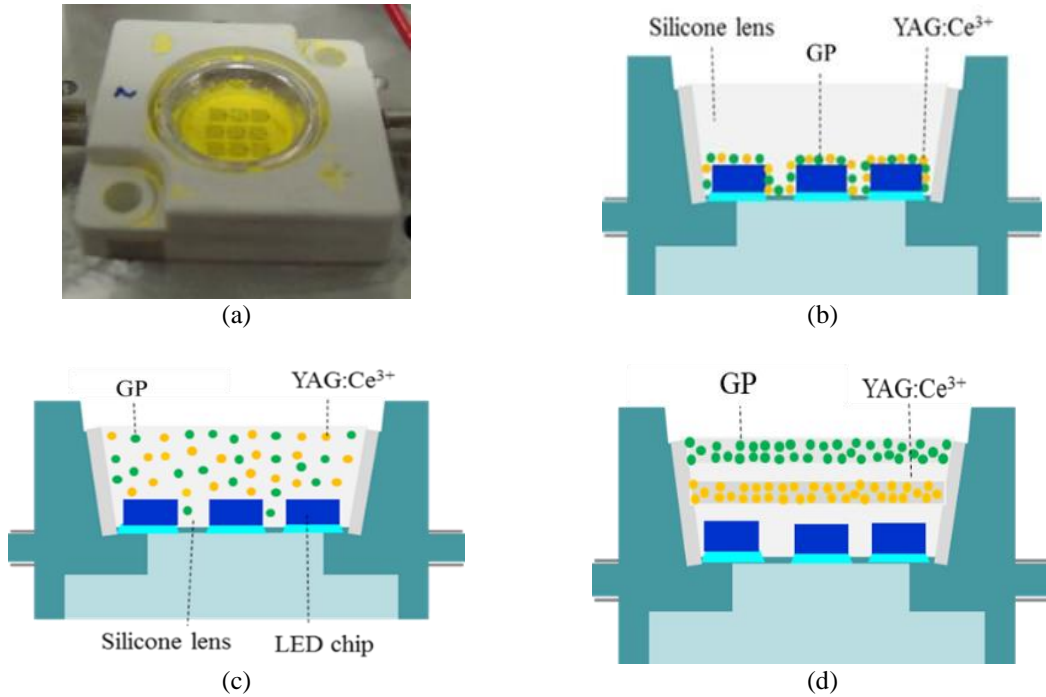
Figure 1. Phosphorus-converting MCW-LEDs demonstration of doping $CaO:Sb^{3+}$; (a) the genuine MCW-LEDs, (b) conformal phosphorus geometric (CPG), (c) in-cup phosphorus geometric (IPG), and (d) regional phosphorus geometric (RPG)
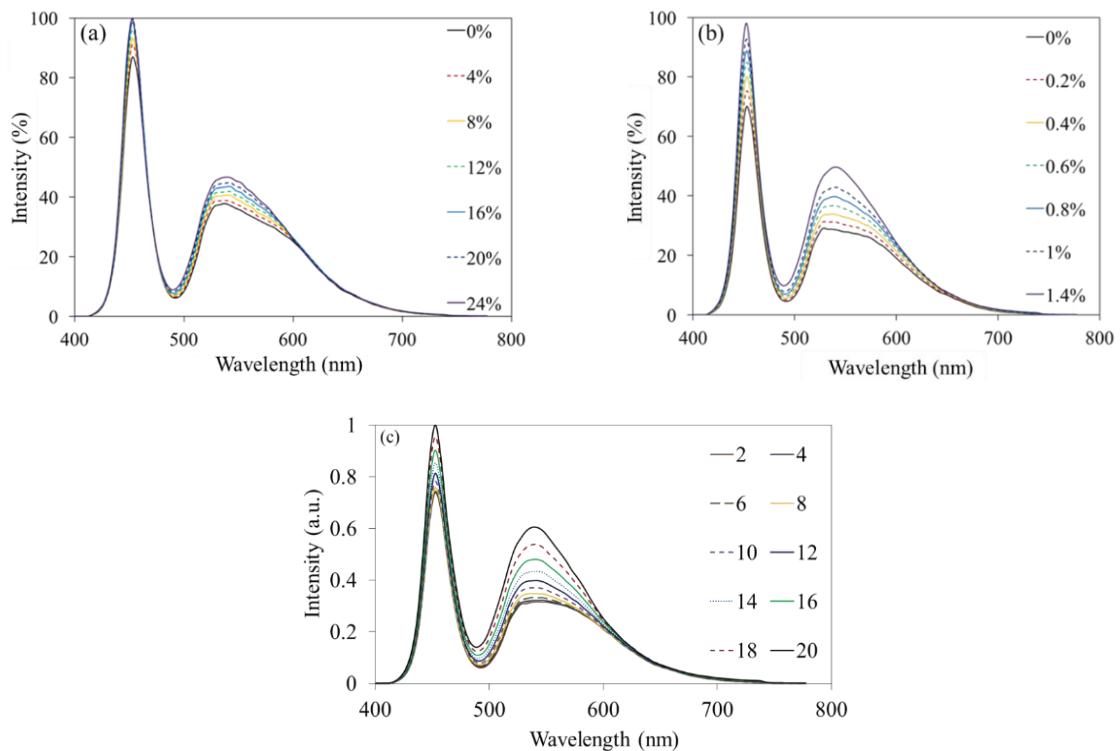

Figure 2. Emitting spectrum of various phosphoruses, (a) CPG, (b) IPG, and (c) RPG

3. ANALYSIS AND DISCUSSION

Scattered coefficient μ_{sca} is calculated using the Mie theory [20]-[23] to validate the optic characteristics of phosphor compounding. The equations below describe the relationship between the scattered coefficients (SC) and the wavelengths, and also the CaO:Sb^{3+} phosphorus ions diameter:

$$\mu_{sca}(\lambda) = \frac{c}{\bar{m}} \bar{C}_{sca}(\lambda) \tag{1}$$

$$\bar{C}_{sca}(\lambda) = \frac{\int^{\int} C_{sca,D}(\lambda) f(D) dD}{\int^{\int} f(D) dD} \tag{2}$$

$$\bar{m} = \frac{\int^{\int} m_i(D) f(D) dD}{\int^{\int} f(D) dD} \tag{3}$$

$$C_{sca}(\lambda) = \frac{P_{sca}(\lambda)}{I_{inc}(\lambda)} \tag{4}$$

The dimension dispersion is denoted by $f(D)$, the phosphorus concentration (g/cm^3) by c, and the scattered cross-section of the phosphorus with unit dimension D by $C_{sca,D}$. Whereas $\bar{C}_{sca}(\lambda)$ and $\bar{m}$ represent the phosphor's scattered cross-section and ion mass, which are summed along $f(D)$. $P_{sca}(\lambda)$ and $I_{inc}(\lambda)$ are the diffused energy using phosphorus photons and the irradiation degree, respectively.

Figure 3(a) depicts the phosphorus coating's scattered coefficients (SC) with CaO:Sb^{3+} phosphor. It is clear that distinct concentrations of CaO:Sb^{3+} will cause the phosphorus combination's SC vary greatly. Resulting in confirmation of the CaO:Sb^{3+} phosphorus concentration with the before-calculation of CaO:Sb^{3+} scattering to have an effect on the color standard of CPG, IPG and RPG structures. SC tends to evolve when the concentration of CaO:Sb^{3+} is higher, irrespective of particle size of CaO:Sb^{3+}. SC rises more markedly at particle sizes of about 1 μm than at larger sizes, resulting in the advancement of color homogeneity. The phosphorus coating's SC index is steadier when CaO:Sb^{3+} particle size is around 7 μm, despite the rise in its concentration, Figure 3(b). This will greatly improve LEDs colour quality scale (CQS). Consequently, as long as CQS is the objective, the CaO:Sb^{3+} diameter around 1 or 7 μm might be an option. Clearly, the SC figure is affected by CaO:Sb^{3+} concentration and size, which is the reason why CaO:Sb^{3+} can be used to improve the illuminated performance and color standard of LEDs.
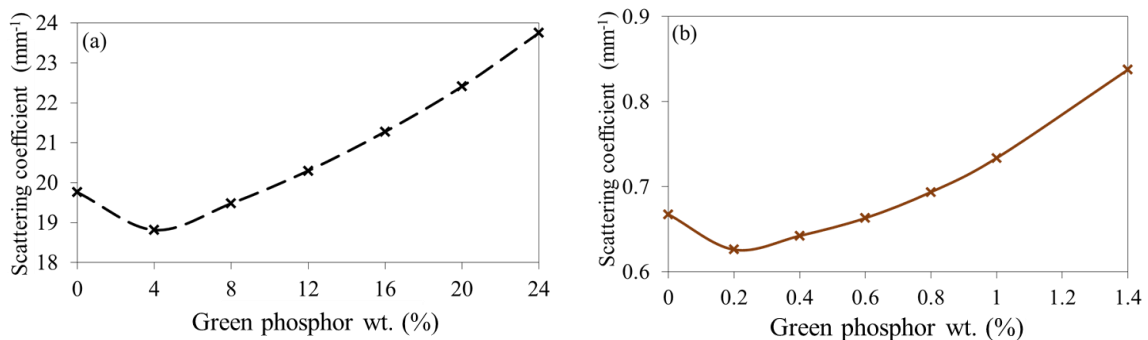

Figure 3. CaO:Sb^{3+} concentration and measurement functions as phosphorus compound's scattered rates at 453 nm (a) CPG and (b) IPG

In this paper, it is highly necessary to fulfill the LED product specification requirement. As a result, MCW-LED demands to work in the range of a 8500 K median CCT value. Furthermore, as CaO:Sb^{3+} phosphorus concentration rises, that of yellow-emitted YAG:Ce^{3+} phosphor ought to be significantly lowered for stabilizing the pre-determined CCT of 8500 K. LED phosphorus sheet's weight percentage is demonstrated [24], [25]:

$$\sum W_{pl} = W_{yellow\ phosphor} + W_{silicone} + W_{yellow-green\ phosphor} = 100\% \tag{5}$$

In this equation, $W_{silicone}$, $W_{yellow\ phosphor}$ and $W_{yellow-green\ phosphor}$ represent the volume percentages of silicon adhsive, yellow-emitted YAG:Ce^{3+} phosphorus, and yellow-green-emitted CaO:Sb^{3+} phosphorus, correspondingly. As shown in Figure 4(a), the MCW-LEDs' angled color variation depends on the presence or absence of CaO:Sb^{3+}. With the addition of CaO:Sb^{3+}, the CCT peak-valley divergence is reduced dramatically. Particularly, the geographical colour dispersion of MCW-LEDs is significantly smoother compared when CaO:Sb^{3+} is absent. This is a compromise among the two performance variables and the optimization issue. If we only enhance one element, the optic system will be feebly optimized in other areas, thus the optimal CQS figures as well as the efficacy of the white-colored LED module will not be obtained concurrently. Just one single factor can lead to the desired output, see Figure 4(b) and Figure 4(c). The solution is that if we want to obtain an excellent CQS, we must use a wide source spectrum and improve performance at 555 nm monochromatic radiation. CQS, lighting beams, as well as CCT P-V variation rates includes three contending features in this research.

The simulated outcomes in Figures 5(a), Figures 5(b) and Figures 5(c) show that luminous production increases with CaO:Sb^{3+} concentration. Furthermore, the findings indicated that the greater the CaO:Sb^{3+} concentration exhibited, the better the beams of light achieved, but the CQS seems to be reduced. Furthermore, when the concentration of CaO:Sb^{3+} decreases but not noticeably, it allows MCW-LED packages to achieve greater correlated color temperature homogeneity and higher beams of light. As demonstrated and proved in previous researches [17]-[19], the green light is beneficial to the lumen output while the red light benefits the CQS, see Figures 6(a), Figures 6(b) and Figures 6(c). In this research, lumen output and CQS depend much on the three basic colors yellow, red and green which can be adjusted by controlling the three phosphor layers. When the concentration of CaO:Sb^{3+} increases, the green light component increase, and the white light spectra considerably grows in the range of 500 nm-600 nm, resulting in a better emitted luminous flux. However, if the green light components exceed the limit amount, the lumen and CQS will decrease significantly. Therefore, this study proposes the appropriate concentration selection of CaO:Sb^{3+} for their application.
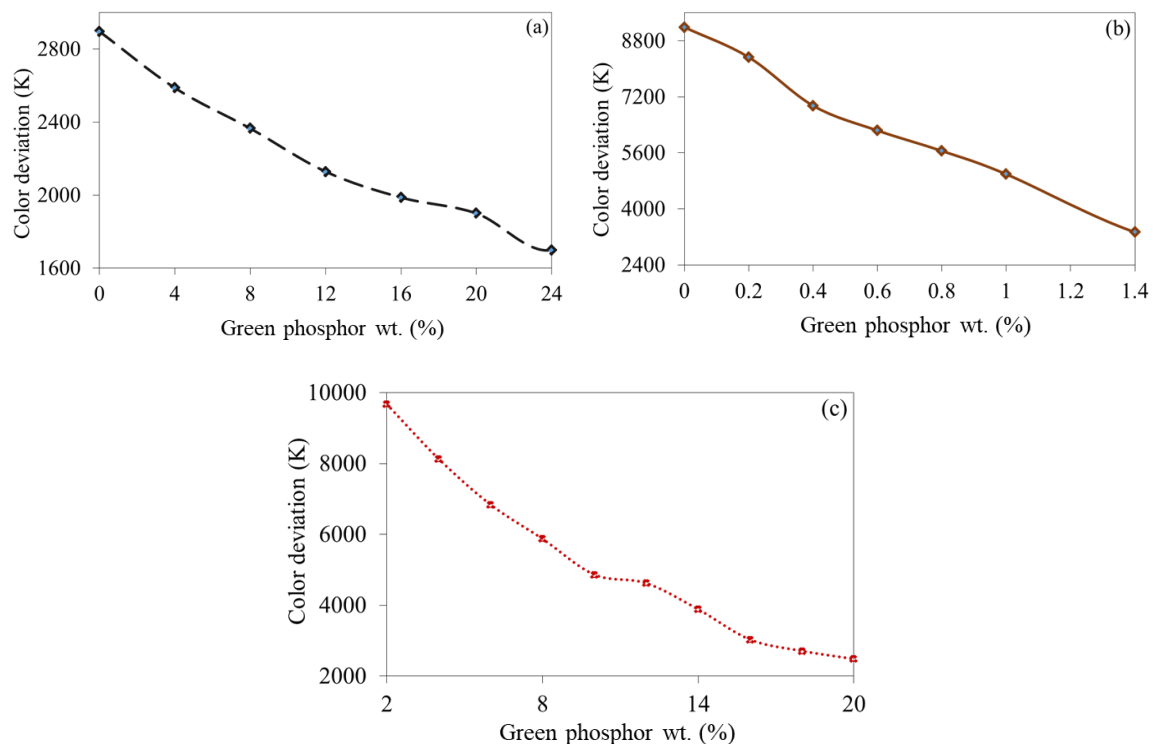

Figure 4. CaO:Sb^{3+} concentration and measurement functions as CCT maximum-valley variation (a) CPG, (b) IPG, and (c) RPG
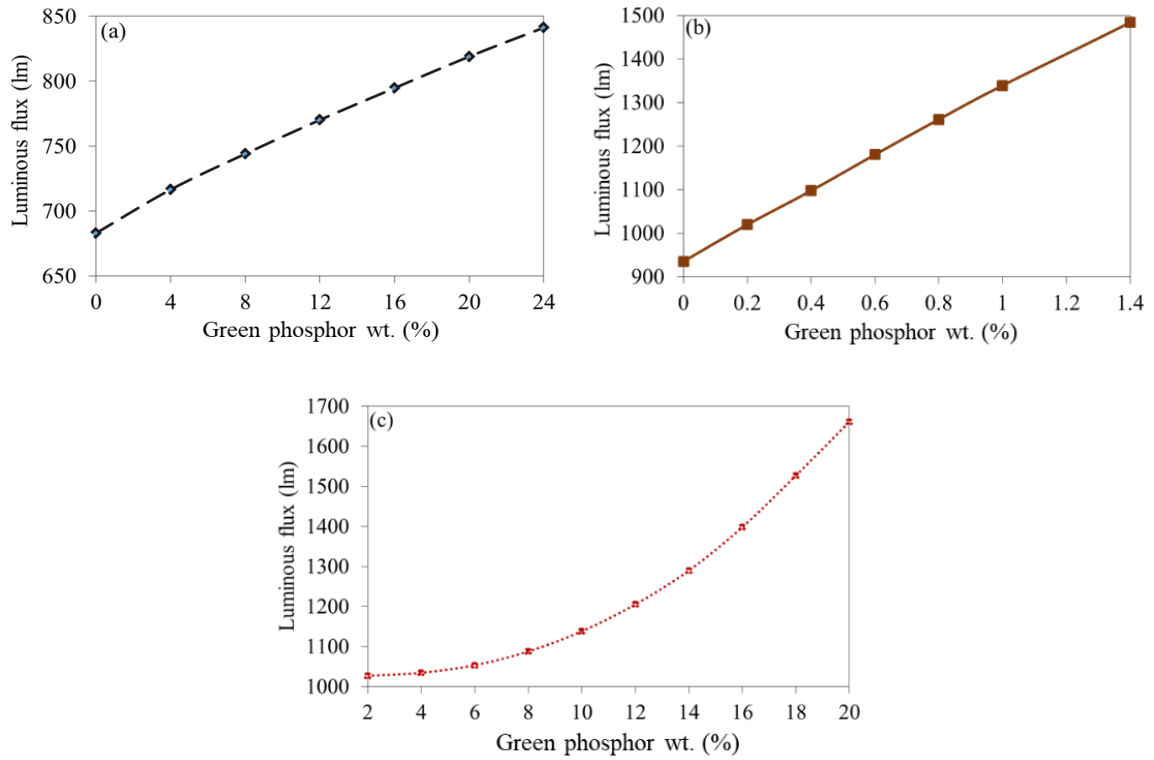
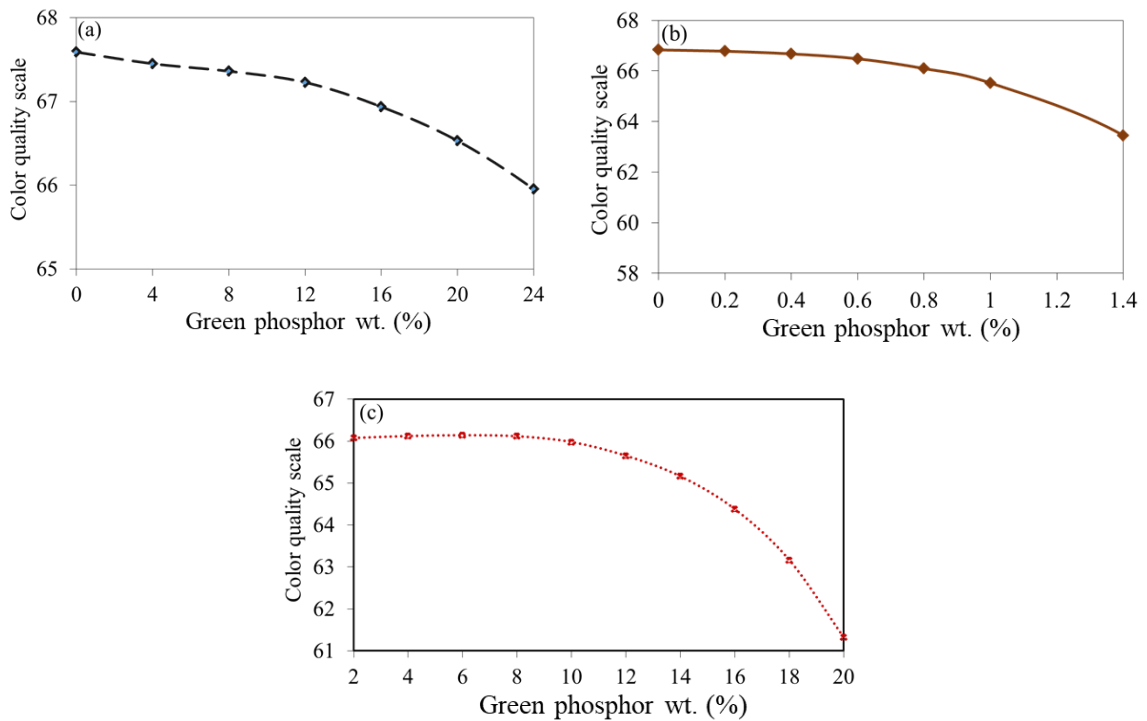Figure 5. CaO:Sb³⁺ concentration and measurement functions as luminescent efficiency (a) CPG, (b) IPG, and (c) RPG

Figure 6. CaO:Sb³⁺ concentration and measurement functions as colour fidelity gauges (a) CPG, (b) IPG, and (c) RPG

4.   CONCLUSION

The primary goal of this research is to show the yellow-green-emitted $CaO:Sb^{3+}$ phosphorus's ability and its potential to improve the color homogeneity and wLED modules' luminous production. To begin, by applying the Mie-scattered principle, chromatic uniformity might considerably enhance regardless the mean CCT or phosphorus layout. The mean of the phosphorus molecule, in particular, influences chromatic homogeneity. Using small $CaO:Sb^{3+}$ particles, around 1 μm or 7 μm, it is possible for the phosphor structures to attain higher and more stable CQS. This is owing to light-scattering compensation in white LED packages. The variance of lumen production is then demonstrated to be dependent on the $CaO:Sb^{3+}$ concentration using Monte Carlo simulation. Undoubtedly, the lumen production increases as the $CaO:Sb^{3+}$ concentration changes.

REFERENCES

[1]   J. S. Li, Y. Tang, Z. T. Li, L. S. Rao, X. R. Ding, and B. H. Yu, "High efficiency solid–liquid hybrid-state quantum dot light-emitting diodes," *Photonics Research*, vol. 6, no. 12, pp. 1107-1115, 2018, doi: 10.1364/PRJ.6.001107.

[2]   P. P. Li *et al.,* "Very high external quantum efficiency and wall-plug efficiency 527 nm InGaN green LEDs by MOCVD," *Optics Express*, vol. 26, no. 25, pp. 33108-33115, 2018, doi: 10.1364/OE.26.033108.

[3]   Y. J. Park *et al.,* "Development of high luminous efficacy red-emitting phosphor-in-glass for high-power LED lighting systems using our original low Tg and Ts glass," *Optics Letters*, vol. 44, no. 24, pp. 6057-6060, 2019, doi: 10.1364/OL.44.006057.

[4]   Y. Liu *et al.,* "Preparation and reliability of flexible phosphor film for warm white LED," *Materials Technology*, vol. 33, no. 1, pp. 22-28, 2018, doi: 10.1080/10667857.2017.1376787.

[5]   V. Subburaj, D. Jena, P. Perumal, and Y. Mahnashi, "High efficiency two-phase switched-capacitor converter with seven distinct negative voltage ratios for power saving applications," *International Journal of Electronics Letters*, vol. 8, no. 3, pp. 298-303, 2020, doi: 10.1080/21681724.2019.1600728.

[6]   Y. Luo *et al.,* "White-light emitting diodes' spectrum effect on photosynthesis and nutrient use efficiency in Podocarpus macrophyllus seedlings," *Journal of Plant Nutrition*, vol. 43, no. 19, pp. 2876-2884, 2020, doi: 10.1080/01904167.2020.1798999.

[7]   J. Hou *et al.,* "White-light-emitting from single-phased (Ca,Eu,Mn)9Al(PO4)7 phosphor with blue-white-yellow tunable luminescence properties for UV-based LEDs," *Materials Technology,* vol. 34, no. 3, pp. 135-142, 2019, doi: 10.1080/10667857.2018.1540331.

[8]   M. Rajendran, K. Singh, and S. Vaidyanathan, "A novel Sm3+-activated Li3BaSrLn3(MO4)8 [Ln = La, Gd, and Y; M = Mo and W] deep red-emitting phosphors for plant cultivation and white LEDs," *Journal of Information Display*, vol. 22, no. 2, pp. 63-81, 2021, doi: 10.1080/15980316.2020.1831630.

[9]   S. Chen and M. Wei, "LED Illumination and Color Appearance of White-Balanced Images," *LEUKOS*, vol. 16, no. 3, pp. 203-215, 2020, doi: 10.1080/15502724.2018.1533409.

[10]   G. S. Archer, "Effect of two different commercially available white light LED fixtures on broiler hatchability and chick quality," *British Poultry Science*, vol. 59, no. 3, pp. 251-255, 2018, doi: 10.1080/00071668.2018.1436160.

[11]   H. Zhang, Q. Su, and S. Chen, "Recent progress in the device architecture of white quantum-dot light-emitting diodes," *Journal of Information Display*, vol. 20, no. 4, pp. 169-180, 2019, doi: 10.1080/15980316.2019.1650129.

[12]   D. Zhou, G. Yan, W. Zhang, J. Lin, and K. Qiu, "Synthesis and luminescence properties of Zn3B2O6:Eu3+, Li+ red-emitting phosphor for white LEDs," *Ferroelectrics*, vol. 528, pp. 114-121, 2018, doi: 10.1080/00150193.2018.1448654.

[13]   F. Rahman, and A. F. George, "Temporal Luminescence of Broadband Light-Emitting Diodes and Their Use for Generating Customizable White Light," *LEUKOS*, vol. 16, no. 4, pp. 303-314, 2020, doi: 10.1080/15502724.2019.1707684.

[14]   Z. Liu, Y. Liu, C. Pan, Y. Fang, and J. Hou, "K2MnF6/KHF2 red phosphor synthesis by a low temperature way for high color rendering index white light emitting diodes," *Ferroelectrics*, vol. 565, no. 1, pp. 66-76,2020, doi: 10.1080/00150193.2020.1761719.

[15]   H. Y. Kim *et al.,* "Selective Coating of White Silicone to Improve the Optical and Thermal Characteristics of White LED Packages," *ECS Journal of Solid State Science and Technology*, vol. 9, no. 6, pp. 065008, 2018, doi: 10.1149/2162-8777/aba562.

[16]   A. Kokka *et al.,* "Development of white LED illuminants for colorimetry and recommendation of white LED reference spectrum for photometry," *Metrologia*, vol. 55, no. 4, pp. 526, 2018, doi: 10.1088/1681-7575/aacae7.

[17]   M. A. Shafouri, N. M. Ahmed, Z Hassan and M. A. Almessiere, "The Effect of The Wavelength of the LED used to Pump Phosphor Produced from Curcuminoids Dye Extracted from Turmeric (Curcuma Longa L.) to Produce White Light," *IOP Conference Series: Materials Science and Engineering please*, vol. 454, 2018, pp. 012048, doi: 10.1088/1757-899X/454/1/012048.

[18]   W. L. Chiong, A. F. Omar, M. Z. M. Jafri, and C. H. Tan, "Spectroscopic Colour Evaluation under Different White Light Emitting Diode Illumination Angle," *Journal of Physics: Conference Series,* vol. 1083, 2018, pp. 012023, doi: 10.1088/1742-6596/1083/1/012023.

[19]   N. Guan *et al.,* "Colour optimization of phosphor-converted flexible nitride nanowire white light emitting diodes," *Journal of Physics Photonics,* vol. 1, no. 3, pp. 035003, 2019, doi: 10.1088/2515-7647/ab2c84.

[20]   H. Y. Kim *et al.,* "Optimization of InGaN-based LED Package Structure for Automotive Adaptive Driving Beam Headlamp," *ECS Journal of Solid State Science and Technology,* vol. 9, no. 5, 2020.

[21]   Sudirman *et al.,* "Utilization of Light Emitting Diode (LED) lamp with difference color as attractor for fixed lift net as small scale fisheries in Makassar Strait, Indonesia," *IOP Conference Series: Earth and Environmental Science*, vol. 564, no. 1, 2020, pp. 012075, doi: 10.1088/1755-1315/564/1/012075.

[22]   M. Manley, P. Collins, L. Gray, S. O'Gorman, and J. M. Cavana, "Quantifying the radiant exposure and effective dose in patients treated for actinic keratoses with topical photodynamic therapy using daylight and LED white light," *Physics in Medicine & Biology*, vol. 63, no. 3, pp. 035013, 2018, doi: 10.1088/1361-6560/aa9ea7.

[23] A. Vaskuri, P. Karha, H. Baumgartner, and O. Kantamaa, "Relationships between junction temperature, electroluminescence spectrum and ageing of light-emitting diodes," *Metrologia*, vol. 55, no. 2, pp. S86, 2018, doi: 10.1088/1681-7575/aaaed2.

[24] M. E. Raypah, M. Devarajan, and F. Sulaiman, "Effects of Substrate on Thermal and Optical Characteristics of High-Power ThinGaN White LED," *IOP Conference Series: Materials Science and Engineering,* vol. 409, no. 1, 2018, pp. 012032, doi: 10.1088/1757-899X/409/1/012032.

[25] S. Y. Lee *et al., "*Using Self-Aligned Si Barrier to Enhance the Contrast Ratio and Performance of Pixelated Light Emitting Diode for Vehicle Headlamp," *ECS Journal of Solid State Science and Technology,* vol. 10, pp. 045003, 2021, doi: 10.1149/2162-8777/abf47d.

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