Indonesian Journal of Electrical Engineering and Computer Science
Vol. 28, No. 2, November 2022, pp. 724~728
ISSN: 2502-4752, DOI: 10.11591/ijeecs.v28.i2.pp724-728

Hue dual-chromatic calcium chlorosilicate phosphor for light-emitting diode having yellow and white illumination

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Article Info

Article history:

Received Nov 28, 2021
Revised Jul 11, 2022
Accepted Aug 19, 2022

Keywords:

Color quality scale
Luminescence
Mie theory
White light-emitting diodes
YAG:Ce

ABSTRACT

High-thermal solid phase reactions produced a series of bright green-yellow phosphors called $Ca_3SiO_4Cl_2,Eu^{2+},Mn^{2+}$ (CaM). For example, powder dispersed reflection, photoluminescence excitation (PE), and along with emission spectra, were used to determine their luminous characteristics at between 10 K and 450 K of temperature. While the CaM exhibits wide absorption bands in the 250-450 nm range, which matches the near-uv of the InGaN-based chips, they also display two dominant absorptions, attributed to the 5d → 4f Eu^{2+} transformation, as well as the $^4T_{1g}(^4G) \rightarrow {}^6A_{1g}(^6S)$ transfer of the two ions Eu^{2+} and Mn^{2+}, respectively. Increasing the concentration of Mn^{2+} ion reduces the lifespan of the Eu^{2+} ion. This encourages an efficient energy exchange between these two ions. The UV light leakage issue in yellow LEDs was resolved by intergrating with n-UV InGaN chips and CaM. Powerful white LEDs were then created by mixing blue chlorophosphate with CaM. Its color coordinate was (0.3281,0.3071), and the associated color temperature (TC) was 6065 K, while the general hue rendering (Ra) and illuminating effectiveness (11 lm/W) were respectively 84.5 and 11 lm/W.

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1. INTRODUCTION

A new revolution in lighting has occurred with the introduction of white light-emitting diodes (WLEDs), which have superior characteristics than conventional incandescent or fluorescent lights [1], [2]. It is possible to manufacture white LEDs in a variety of methods. Photoluminescence excitation (PC-wLED) which may be divided into two categories: blue (440-470 nm) and n-UV (390-410 nm) InGaN chips coupled with down-converting phosphors. YAG:Ce^{3+} (yellow) is a typical downconverting phosphor for InGaN chips in blue color [3]. Because red emission is rare with such white LEDs, the certainty of response index (CRI) (R_a 80) is poor. It's worth noting, as well, that white LEDs based on the blue InGaN semiconductor have a low color consistency when mass-produced. Since it has a greater output, the n-UV LED is believed to be more reliable and efficient. It is important to understand that the n-UV LED usually produces wavelengths less than 400 nm, which has minimal influence on PC-wLED chromaticity coordinate. Because of its high applicability, it's predicted that these LEDs will be widely used in solid-state lighting [4], [5]. A number of phosphors have been studied. The downside is that they have a poor down-converting effectiveness, weak chemical and thermal stability, or severe synthesis settings. As a result of their high luminous efficacy, low synthesis heat, and physical chemistry durability, Eu^{2+}-activated chlorosilicates have recently received greater interest from researchers [6]-[8]. An orange-yellow phosphor made from $Ca_3SiO_4Cl_2$,Eu^{2+},Mn^{2+} (CaM) (green) was created by Liu and colleagues in 2005, however its CRI was poor due to a lack of blue or green component. There is a set of strong green/yellow dual-chromatic phosphors called CaM described in this study. Methodically, the very effective resource transmit among Eu^{2+} and Mn^{2+} ions was investigated in great detail. It was also possible to produce strong yellow LEDs with minimal UV leakage and high bottom efficiency along with optimal CRI and luminance efficiency WLEDs based on CaM, which is a breakthrough [9]-[11].

2. EXPERIMENTAL DETAILS

To make CaM powder, a solid-state process was at high temperatures was applied. $CaCO_3$, $CaCl_2$, SiO_2, and $MnCO_3$ (99.99%) were used as source materials. All raw ingredients were mixed and grounded in ratios 2:1:1.1 of $CaCO_3$, SiO_2, and $CaCl_2$ with the a small addition of Eu_2O_3 and $MnCO_3$ in an agate mortar and pestle. For 4 hours, they were maintained at 1123 K in 25% H_2/75% N_2 environment for 4 hours before being removed from the corundum crucible. Finally, samples were gently cooled to ambient temperature in a nitrogen environment within the tube furnace after they had been produced. Describes the solid-state process that produced $Y_3Al_5O_{12}$:0.06Ce [12], [13]. Powder scattering spectra, Eu^{2+} single doped specimens, and Eu^{2+}-Mn^{2+}-codoped ones. High reflection of phosphor is strong from 350 to 800 nm, and then drops drastically to 200nm owing to host absorption. On the basis of Figure 1, we may calculate that the low-energy side of the host absorption is about 5.4 eV. There are two wide bands that result from the 4f–5d electronic dipole that allow conversions of Eu^{2+} ions when it is doped singly into the host. There are two wide bands that result from the 4f–5d electronic dipole that allow conversions of Eu2+ ions (4f6-5d) when it is doped singly into the host. CaM has a similar spectrum, with the exception of the increased absorption. Metal–ligand charge carrier band of Mn^{2+}–O_2 along with prohibited transitions of Mn^{2+} ion may also contribute to enhanced absorption intensity in the 250-550nm range.

A dual exponential equation gives a good match to all decay graphs [14].

$$I(t) = I_0 + Ae^{-t/\tau_1} + Be^{-t/\tau_2} \quad (1)$$

A and B represent the constants, while I_0 and I indicate the luminescence intensities at time zero. The duration of the exponential contents are written as τ_1 and τ_2.

Following is a formula for calculating the power transmission efficiency (η_T) from Eu^{2+} to Mn^{2+} [15]:

$$\eta_T = 1 - I_d/I_{d0} \quad (2)$$

when the donor Eu^{2+} ion is absent from Mn^{2+}, I_{d0} and Id are the respective intensities of donor Eu^{2+} ions. At the same time, there is also an energy transfer efficacy, written as η_T. When the concentration of Mn^{2+} dopant increases, so does the energy transfer efficiency η_T until it reaches saturation [16], [17]. This is quite similar to the $Ce^{3+} \rightarrow Eu^{2+}$ of $BaZnS_3$.

3. RESULTS AND ANALYSIS

According to Figure 1, there is a reversal change in the ratio of green CaM to yellow YAG:Ce^{3+}. Aside from maintaining the average CCTs, this modification also influences the absorption and scattering in WLEDs with double phosphors. This has a direct influence on the hue richness and lighting beam performance of WLEDs. As a consequence, the hue fidelity of WLEDs is specified by the phosphor's concentration. When the CaM was increased to 20%, YAG:Ce^{3+} concentration decreased for keeping average CCTs [18]-[20]. The same is true for WLED models having the CCT area of 5600-8500 K.

According to Figure 2, green CaM dosage affects the transmittance spectrum of white LEDs. A variety of options are available, depending on the requirements of the producers. A WLED aiming to acquire higher chromaticity is allowed to decrease its flux intensity slightly. Figure 2 also demonstrated that the white light consists of several spectral regions, primarily 420-480 nm and 500-640 nm. 5600 K, 6600 K, 7700 K, 7700 K and 8500 K spectra are shown in these five figures in the order listed. As can be seen, the intensity of light in two regions (420-480 nm and 500-640nm) tends to increase with the phosphor's dosage. As the two-band spectrum expands, the luminous flux rises. The blue-light dispersion in the phosphorous film and in WLEDs has risen, which means that color consistency will be preferred. When using CaM, this is a critical outcome. In particular, it is challenging to regulate the color homogeneity of the distant-phosphor arrangement at great values of WLED’s CCT. From the presented finding in this study, CaM can boost the hue standard of WLEDs, even at low color (5600 K) or elevated hue heats (8500 K) [21].

The efficacy of luminosity from the simulated two-film distant phosphor is displayed to affirm the benefit of using CaM phosphor. According to Figure 3, CaM-concentration increases (2-20% wt.) obviously result in the substantially increased luminous flux. When CaM concentrations were increased in all three median CCTs, hue divergence was considerably reduced, as seen in Figure 4. This can be explained by the red phosphor's absorption. It's the CaM that absorbs and turns the original blue color from the LED chip into green illumination. Additionally, the CaM also absorbs yellow light in extra to the blue coming from the LED chip. According to the absorbing characteristics of phosphor particles, the blue light is easier to be absorbed than the yellow light; in other words, the blue-radiation absorption is more significant than the other. In WLEDs with the existence of CaM, this leads to more green-light elements to be generated, promoting the uniform color distribution, which is regraded as a critical feature for high-fidelity WLEDs. Therefore, the white light that has great ability to re-create the object's colores faithfully probably adds more value to the WLED lamps and contributing to increasing these illuminating devices' prices. CaM phosphor utiluzation is beneficial to the production cost, meaning that CaM is broadly applicable.

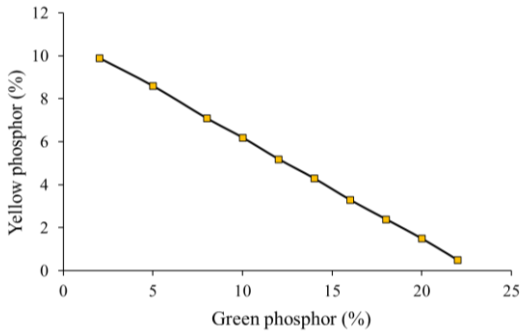

Figure 1. Modifying the dosage of phosphor to preserve the mean CCT

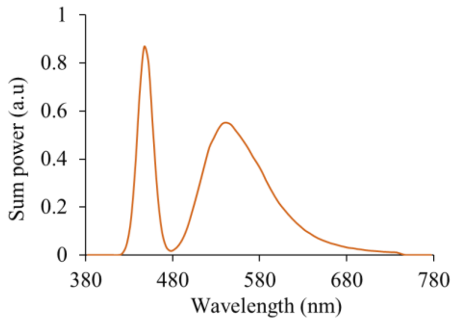

Figure 2. The emitting spectra of 7000 K WLEDs as a function of CaM dosage

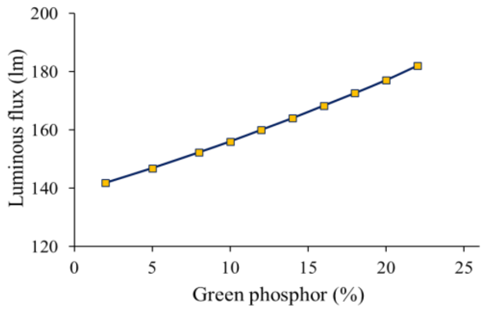

Figure 3. The luminous flux of WLEDs as a function of CaM dosage

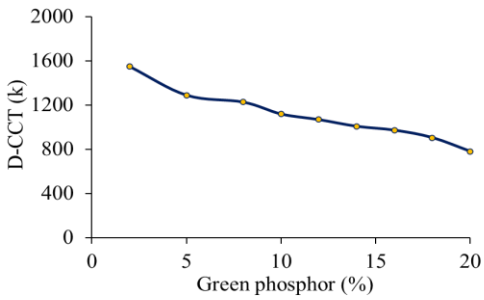

Figure 4. The color deviation of WLEDs as a function of CaM dosage

Besides the hue uniformity, to get the better fidelity of white light for the WLED, the color rendition intent is also imperative. This means the WLED with good chromatic fidelity needs both adequate chromatic uniformity and great color rendition efficiency [22]-[24]. The color rendering index, shortened as CRI, one of the most used metrics for assessing an object's ability to disclose its actual color when illuminated by a tested light source. Besdies, as the CRI was reported to display a mismatch in the results, the color quality scale, abbreviated as cultural intelligence scale (CQS), was invented for overing coming such a drawback. This article examines both CRI and CQS for the color re-cration efficiency of the WLED's white light when using CaM green phosphor, as displayed in Figure 5 and Figure 6, respectively. If the green light proportion is excessive to dominate the distribution on the chroma scale, the other primary colors (blue, yellow, and orange-red) will be shortage, leading to the degraded color fidelity. In Figure 5, CRI shows a continuous decline as the concentration of CaM rises, due to the mentioned reason. In cases of the CQS, in Figure 6, we can observe an increase as the concentration of green-phosphor CaM is from 2-10% wt. The increase in CQS can outweigh the effect of decreasing CRI because CQS covers the CRI, color coordination, and observer's preference. This means it is more significant and requires more effort to achive the adequate CQS [25]. These three essential elements make CQS a close approximation of a genuine color quality index. As seen in Figure 6, CQS is boosted in the presence of the distant CaM layer. The concentration has no effect on CQS, and the concentration is less than 10% wt has no effect on CQS. There is a severe color loss when green dominates when CaM concentrations are greater than 10% wt. If you want to use green phosphor CaM, the right concentration is neccessary.

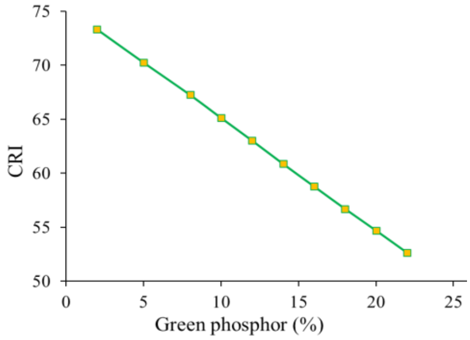

Figure 5. The color rendering index of WLEDs as a function of CaM dosage

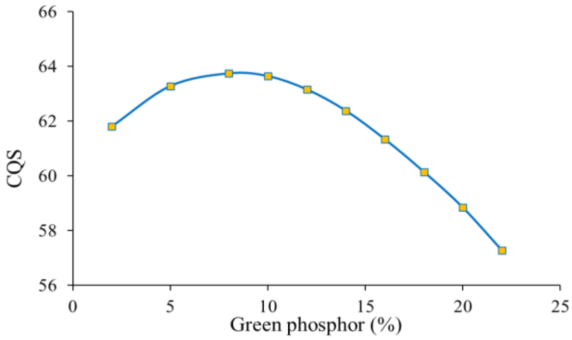

Figure 6. The hue quality scale of WLEDs as a function of CaM dosage

4. CONCLUSION

A sequence of bright yellow phosphors, CaM, has been discovered and described. Because of their broad absorption band and adjustable emission, as well as their high efficiency energy transfer between the ions, they have good color stability with rising temperature. In contrast, the CaM yellow LED has considerably lower UV leakage than the yellow LED based on CaM. Its specifications: 0.3281, 0.3071; 6065 K; 84.5 lm/W; and 11 lumens per watt (lm/W).

ACKNOWLEDGEMENTS

This study was financially supported by Van Lang University, Vietnam.

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