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Impact of green-emitting $CaSc_2O_4$: Ce^{3+} phosphor on the illuminance and color uniformity of white-light-emitting diodes

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ABSTRACT

With blue light stimulation, a novel green phosphor, Ce^{3+} -activated $CaSc_2O_4$, was created, which emits green illumination with a maximum wavelength of 515 nm. Since the brightness performance of Ce^{3+}-activated CaSc2O4 is equivalent to that of commercial phosphors such as $Y_3Al_5O_{12}$: Ce^{3+}, it may be utilized as a substance for chroma transformation in white-light-emitting diodes (WLEDs) that comprise one blue LED, one green phosphor, as well as one red phosphor. The Ce ion is most likely at an eight-coordinated Ca position in the base crystal for said phosphor, which posesses orthorhombic $CaFe_2O_4$ configuration. The effect of burning temperature and dopant concentration on luminous strength was examined, and it was discovered that the optimal temperature and concentration reached 1,600 °C and 1 mol % Ce replaced in the Ca site, respectively. By substituting Mg for Ca, the luminous maximum wavelength moved towards greater values. Substituting Ca using Sr, on the other hand, and yielded changes towards lesser wavelengths.

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1. INTRODUCTION

Light-emitting diodes (LED) devices with a phosphor and an elevated-performance InGaN LED are becoming widely available commercially [1]. The phosphors employed here must absorb blue or UV illumination with a long wavelength. Many phosphors have been suggested for this application, including oxides, sulfides [2], and nitrides [3], [4]. The most common white LED (WLED) comprises one blue InGaN LED and $Y_3Al_5O_{12}$: Ce [5], [6]. Said WLED yields very little light of red, thus having undesirable chroma rendition index (CRI). The usage of red and green phosphors rather than yellow phosphors has been recommended as a solution to this issue [7]. $Ca_3Sc_2Si_3O_{12}$:Ce^{3+}, a green phosphor, was created specifically for this application [8]. The phosphor's host crystal has a garnet structure. The $Y_3Al_5O_{12}$: Ce^{3+} yellow phosphor, which is the most frequently utilized phosphor for white LEDs, has a configuration that is almost identical to this. $Lu_2CaMg_2Si_3O_{12}$: Ce^{3+}, a phosphor with a garnet-kind host crystal and Ce^{3+} as an activator, has also been described [9]. As a result, Ce^{3+} may effectively display long-wavelength illumination from green to red in a host crystal with a garnet structure, independent of the components present. Calcium sulfide is one of the host crystals in which Ce^{3+} ions show long-wavelength illumination, in addition to garnet [10]. Apart from garnet, no oxide host crystal has been identified as a host crystal for long-wavelength Ce^{3+} illumination. A new phosphor made up of an oxide host crystal other than garnet and Ce^{3+} activator is described in this paper. This phosphor emits a great amount of green light. The connection among the phosphor's crystal structure and its illumination characteristics is also discussed.

2. METHOD

The $CaSc_2O_4:Ce^{3+}$ phosphor was made by a standard solid-status process. Powders of $CaCO_3$, Sc_2O_3, and CeO_2 were weighed and combined. Ca: Sc: Ce=0.99:2.00:0.01 was a particular atomic ratio of the elements. The concentration of cerium was increased from 0.05 to 5 mol%. The combined raw resources were put on platinum foil and heat-trated within 180 minutes under 1,400-1,600 °C within 4% H_2+N_2 surrounding. $SrCO_3$, MgO, and Lu_2O_3 were utilized as raw resources in the research that involved replacing Ca or Sc with some other element. In relation to the Ca content, the Ce concentration was set at 1 mol%. An F4500 fluorescence photometer was used to evaluate luminescence and luminescence stimulation spectra (Hitachi). X-ray diffraction (XRD) was conducted via a Cu-Kα X-ray source and the X'Pert MPD (PANalytical) application. SrY_2O_4: Ce^{3+}, SrY_2O4: Eu^{3+}, SrY_2S_4: Ce^{3+}, and SrY_2S_4: Eu^{2+} are some of the phosphors with the $CaFe_2O_4$ configuration that have been described. SrY_2O_4: Ce^{3+} is the only one of them with a Ce^{3+} activator in an oxide host. Manivannan et al. observed two forms of illumination for the phosphor: 570 nm light from a "Ce^{4+}-O_2" charge-transfer conversion and 475 nm illumination from the Ce^{3+} 4f-5d conversion. In our work, nevertheless, the last illumination was not seen at room temperature. Manivannan et al. also claimed a spectrum that was recorded at 10 K. According to the findings from this study, Ce^{3+} in the SrY_2O_4 host crystal is quenched and does not display effective illumination at normal temperature [11], [12]. SrY_2S_4: Ce^{3+} has been claimed to display illumination by Ce^{3+} in sulfides with the $CaFe_2O_4$ configuration. Therefore, it is ineffective as a phosphor. $CaSc_2O_4$ is the first $CaFe_2O_4$-type host crystal in which Ce^{3+} exhibits effective luminescence at room temperature, as seen following. The existence of a Sc ion, which is not usual in phosphor host crystals, creates an adequate crystal field for illumination, albeit the cause for this is unclear. To figure out how the illumination works, more research is needed.

3. RESULTS AND DISCUSSION

We can see that there is an opposite change for the dosages for phosphorus $CaSc_2O_4$: Ce^{3+} as well as phosphorus YAG: Ce^{3+} in Figure 1. This change serves two purposes: it maintains average central choroidal thickness (CCTs) [13], [14] while also affecting the absorptivity as well as dispersion in the WLED device containing a pair of phosphor sheets, affecting chroma performance as well as efficacy of the illuminating flux of said device. The $CaSc_2O_4$: Ce^{3+} concentration used thus affects the chroma outout in the device. The YAG: Ce^{3+} dosage declined, sustaining the mean CCT avlues as the $CaSc_2O_4$: Ce^{3+} scale climbed from 2 percent to 20 percent Wt. WLED apparatuses having chroma heat levels ranging between 5600K and 8500 K are comparable to this as well.

Figure 2 depicts the luminescence as well as luminescence stimulation spectra of the $CaSc_2O_4$: Ce^{3+} phosphor. Ce^{3+} has a 5d-4f conversion, which causes luminescence. The luminescence maximum was found around 515 nm, with a shoulder on the longer wavelength side due to the splitting of the Ce^{3+} ion's 4f base state. The luminescence stimulation spectrum has a maximum wavelength of 450 nm. This is a substance that may be used to convert the color of a white LED into a blue InGaN LED. The luminous performance was around 90% of $Ca_3Sc_2Si_3O_{12}$: Ce^{3+}, which also includes Sc, and was larger than that of a commercial yttrium aluminum garnet (YAG) phosphor (P46-Y3 by Kasei Optonix). Figure 3 provides a comparative analysis of luminescence spectra with stimulation at 455 nm. The following is a comparison among $CaSc_2O_4$: Ce^{3+} and $Ca_3Sc_2Si_3O_{12}$: Ce^{3+}. Raising the synthesis temperature improved the light strength, and the phosphor produced at 1,600°C had the highest effective illumination. Higher synthesis temperature enhanced crystallinity, which likely increased illumination effectiveness. Figure 2 also illustrates the influence of the $CaSc_2O_4$: Ce^{3+} dosage upon the transference spectrum in the WLED apparatus. When using $CaSc_2O_4$: Ce^{3+}, this is a noteworthy result. As a consequence, our research suggests that $CaSc_2O_4$: Ce^{3+} can enhance WLED color quality at low hue temperatures (5600K) and high hue temperatures (8500K) [15], [16].

As a result, the research proved the efficiency for the generated illumination of this two-layer remote setting. Figure 3 displays the increase of the $CaSc_2O_4$: Ce^{3+} concentration from 2% wt. to 20% wt., resulting in a considerable improvement in illumination. In Figure 4, the color deviation was considerably decreased regardless of CCT when concentrations of $CaSc_2O_4$: Ce^{3+} were used. The green illumination presence in the WLED device increases when $CaSc_2O_4$: Ce^{3+} is added. Based on this, the chroma consistency improves. The pricier the WLED white illumination, the greater the color uniformity indicator [17]–[19]. Therefore, one of the most significant WLED characteristics right now is color uniformity. $CaSc_2O_4$: Ce^{3+}, on the other hand, is quite cheap. As a result, $CaSc_2O_4$: Ce^{3+} has recently been employed in a variety of applications [20]–[22].

Chroma uniformity would be among the many factors utilized for appraising the chroma performance in WLED apparatuses, therefore a high chroma uniformity indicator cannot be used for indicating color quality excellence. Instead, the researchers created a color rendering indicator as well as chroma quality scale. The chroma rendition index assesses the real hue in a thing. When green light presence in the primary chromas (yellow, green, blue) is excessive, chroma disparity occurs [23], decreasing hue fidelity, which has a significant influence on WLED's hue standard. In Figure 5, when the phosphors layer is remote from $CaSc_2O_4$: Ce^{3+}, the CRI decreases slightly. CRI, on the other hand, are permitted since they fill a gap in the CQS, which would be a more important and difficult indicator to attain [24]–[26]. The hue rendering indicator, the selection of the viewers, and the hue coordinate are all part of the CQS index. CQS is used as a general indicator of color quality. CQS increases in the presence of a distant $CaSc_2O_4$: Ce^{3+} phosphor layer, as seen in Figure 6. Additionally, when the concentration of $CaSc_2O_4$: Ce^{3+} was below 10% wt, CQS did not change substantially as the $CaSc_2O_4$: Ce^{3+} content was increased. When the concentration of $CaSc_2O_4$: Ce^{3+} exceeds 10% wt., CRI as well as CQS would be considerably reduced, caused by severe hue penalty caused by the green color of $CaSc_2O_4$: Ce^{3+} taking up too much space. In general, while utilizing green phosphor $CaSc_2O_4$: Ce^{3+}, it is important to choose a suitable concentration carefully.

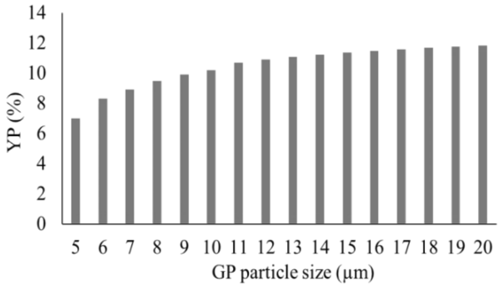

Figure 1. Adjusting the phosphor concentration to maintain the median CCT

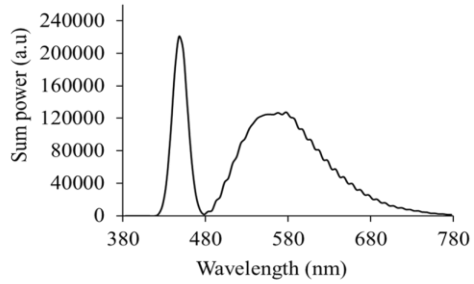

Figure 2. The emission spectra of 5000K WLEDs as a function of $CaSc_2O_4$:Ce^{3+} size

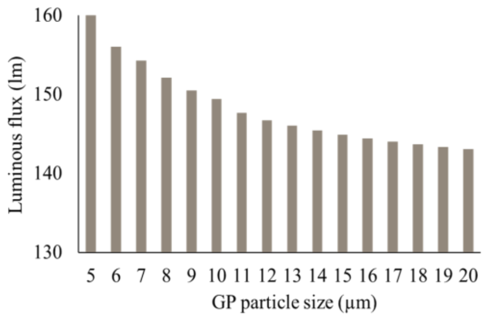

Figure 3. Relation between the lighting flux from the WLED device and $CaSc_2O_4$:Ce^{3+}size

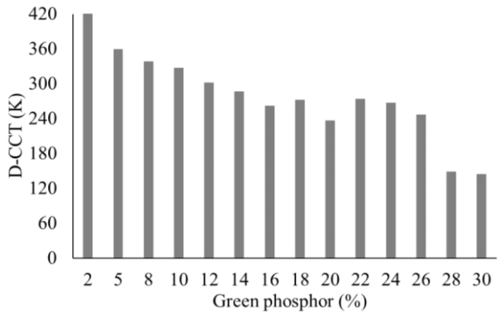

Figure 4. Relation between the hue aberration from the WLED device and $CaSc_2O_4$:Ce^{3+}size

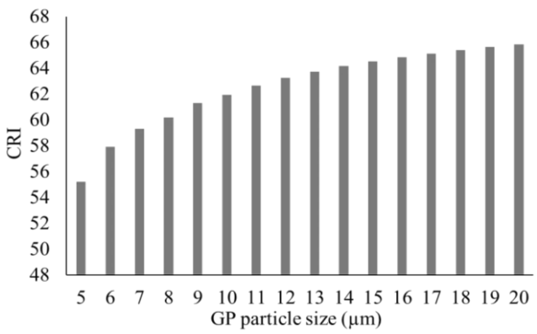

Figure 5. Relation between CRI from the WLED device and $CaSc_2O_4$:Ce^{3+}size

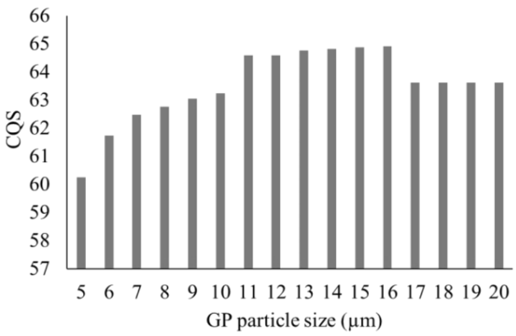

Figure 6. Relation between CQS from the WLED device and $CaSc_2O_4$:Ce^{3+}size

4. CONCLUSION

A novel green phosphor, $CaSc_2O_4$: Ce^{3+}, has been created, consisting of an oxide host crystal with a $CaFe_2O_4$ structure and a Ce^{3+} activator. This phosphor is intended to be used as a hue transformation substance for white LEDs with good hue rendering. The crystal field of Ce^{3+} and its luminous properties were addressed in this paper in contrast to $Ca_3Sc_2Si_3O_{12}$: Ce^{3+}. For luminescent characteristics, the influences of heating temperature and activator concentration were investigated. The illumination maximum shift and reduction in illumination strength were detected when the component elements of the host crystal were substituted.

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