Photoluminescence study of Ce$^{3+}$ activated blue emitting Ca$_{14}$Al$_{10}$Zn$_6$O$_{35}$ lamp phosphors

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Abstract. The photoluminescence analytical study of Ce$^{3+}$ doped Ca$_{14}$Al$_{10}$Zn$_6$O$_{35}$ phosphors is done in this research work. Powder X-ray diffraction technique (XRD) along with scanning electron microscope i.e. (SEM), CIE colour coordinates including their PL properties with emission intensity effect too were analyzed for the characteristics of prepared phosphors. In the instance of Ca$_{14}$Al$_{10}$Zn$_6$O$_{35}$:Ce$^{3+}$, the emission spectra demonstrates an exclusive 442 nm centered band corresponding to Ce$^{3+}$’s 4f–5d transition. The result specifies that the Ce$^{3+}$ activated Ca$_{14}$Al$_{10}$Zn$_6$O$_{35}$ phosphor could find out applications in the light phosphor production.

Keyword: Photoluminescence, XRD, SEM, CIE.

1. Introduction
Synthetic alkaline rare earth aluminates enabled by Ce$^{3+}$ ions are professional luminescence compounds, exhibiting a blue emission marked by excellent quantum output under UV excitation [1]. They are commonly used in PDPs, field emission displays (FEDs), and fluorescence lamps [2, 3]. The solid–state reaction process usually produces alkaline earth aluminate phosphors. Combustion synthesis is a new method introduced to the production of phosphor over the last few years [4]. Synthesis of the combustion involves an exothermic reaction among metal nitrates and a fuel. This method creates the as- synthesized state of strongly crystalline powders. Within this paper the specimen of the Ce$^{3+}$ co-doped Ca$_{14}$Al$_{10}$Zn$_6$O$_{35}$ were synthesized through an easy process of combustion. We investigated their emission and excitation spectra, and identified a blue afterglow. The effectiveness in luminescence can be significantly improved when phosphors are doped with appropriate supplementary activators [5]. Owing to Ce$^{3+}$’s strong spectroscopic properties and its aptitude to integrate Ce$^{3+}$ ion into a lot of unique host resources, Ce$^{3+}$ enabled components have created increasing interest in a variety of applications. [6]. These all-prepared materials incorporate greater returns, emission wavelength with adequate reaction, rapid luminosity decreases in testing and stable temperatures, rendering them desirable for use in high energy branch of physics study [4] as well as in medicinal imaging applications [5]. On the basis of outstanding luminescence properties, inorganic activated Ce$^{3+}$ materials are therefore used for ionizing radiation in displays, lighting systems and certain other applications. [7]. Ce$^{3+}$ can be sustained in the oxidation state of a host material. The luminescence inquiries studied and checked the stability and incorporation of Ce ions into the sample. For the reason that positive spectroscopic property of Ce$^{3+}$ also the potential to
combine Ce$^{3+}$ ion into different host inorganic substance that has been activate by means of cerium ion cover up, several applications are of interest [8].

Inorganic materials that are activate by Ce$^{3+}$’s ions be therefore used within lighting applications, sensors with ionizing radiation display systems, with the benefit of superb luminescence properties [9]. It is also used as a guide ion to analyze the 5d energies of an additional rare earth ion in similar host lattice material of Ce$^{3+}$ ion [10]. Subsequently, the study of the spectroscopic property belonging to Ce$^{3+}$ ion in a variety of host material is essential for in cooperation to the basic function and the scientific studies. White light generation, either by means of a arrangement of fundamental colours or else related colours owing to white light produced by UV-blue LEDs, by casing LEDs with appropriate inorganic phosphor that are excited with LED lights meant for this sort of inorganic phosphorous altered LEDs that create white colored light, making clear the creation of appropriate phosphorous materials. Currently provided W-LEDs have lower regeneration colours because more often they were not reliant on the arrangement of a blue LED with an inorganic yellow phosphor emitting.

Due to its superior usage features such as good luminous efficiency, energy-saving capability, extended life cycle and shortness of harmful mercury, so white-light-emitting diodes are seen like next era of illumination sources Use of such blue or NUV-LEDs allows a range of perspectives to provide white light [11-12]. In order to achieve the white light Nichia Co., the original commercially produced W-LED in which the blue LED is shielded by YAG is incorporated: Ce$^{3+}$ yellow phosphor.

2. Experimental
The blue-emitting Ca$_{14}$Al$_{10}$Zn$_6$O$_{35}$:Ce$^{3+}$ phosphor was ready at 550$^\circ$C with updated combustion process. The materials used for the start were Ca(NO$_3$)$_2$ (99.99% purity Merck), Al(NO$_3$)$_3$·9H$_2$O (99.99% purity Merck), Zn(NO$_3$)$_2$ (99.99% purity Merck), (NH$_4$)$_2$Ce(NO$_3$)$_6$ (99.99% purity Merck), and ureas (purity Merck). Component of the prepared compound was combined in mortar as per stochiometric ratio and eventually a pasty substance was produced after the substance was moved in the muffle furnace at around 550$^\circ$C. Subsequent to the crushed powder is recovered after that advance examination by mean of XRD as well as photoluminescent measurements and flame formed with the foam powder was produced. The purity process of the prepared substance has been confirmed by X-ray diffraction powder (XRD); PAN-analytical-diffractometer through Cu K$_\alpha$-007 radiation (1.5405 Å) at 30mA and 40 kV operating voltage and scanning stage time at 10.3377 s. A Shimadzu RF5301PC spectrofluorophotometer measured at room temperature is being used to analyze photoluminescent emission (PL) for precise excitation at our workplace.

3. Results and discussion.

3.1. X-ray powder diffraction pattern
X-Ray diffraction tests were conducted at room temperature for this ready sample analysis of the crystalline structure of the phosphorous materials. Figure 1, displays the XRD patterns of the Ca$_{14}$Al$_{10}$Zn$_6$O$_{35}$ phosphors ready. For the analysis of its phase purity as well as crystallinity, the manufactured fine powder compound was distinguished by the use of X-ray powder diffraction (XRD) via a PAN Analytical Xpert Pro diffractometer, which is registered using Cu-K$_\alpha$ radiation (1.54060 nm) with a 10.3377s scanning stage time with continuous scanning form. This Ca$_{14}$Al$_{10}$Zn$_6$O$_{35}$ substance Ce$^{3+}$ ion was developed on the typical available JCPDS Data Source Database Phosphors Comparison and found in outstanding conformity with JCPDS’s Data-Source File Number 050-0426. The XRD sequence of the Ca$_{14}$Al$_{10}$Zn$_6$O$_{35}$ compound is much like follow.
3.2 SEM Study
The SEM images for combustion synthesized Ca$_{14}$Al$_{10}$Zn$_6$O$_{35}$ phosphor under several microns to sub-
few microns are shown in figure 2. This shows that phosphor produced using modified combustion
synthesized process has a sharp morphology of the surface and has crystalline grains.

3.3 Ce$^{3+}$ luminescence in Ca$_{14}$Al$_{10}$Zn$_6$O$_{35}$ phosphors
Photoluminescent excitation as well as emission spectra of Ca$_{14}$Al$_{10}$Zn$_6$O$_{35}$:Ce$^{3+}$ phosphor reveal a
broad absorption band within area of 280-380 nm owing to a 4f to 5d transition of Ce$^{3+}$ ions up to 330
nm. Ca$_{14}$Al$_{10}$Zn$_6$O$_{35}$:Ce$^{3+}$ phosphor photoluminescent emission spectra are in the 442 nm of blue
emitting band as shown in figure 4. Usually, the ground state configuration of Ce$^{3+}$’s ion is divided
into 2 groups, that is, $^2$F$_{5/2}$ and $^2$F$_{7/2}$, whereas the excited configuration of 5d is divided into a crystal
playing area of 2 to 5 members. The transfer of electrons from the excited state of $^2$D$_{1}$ to Ce$^{3+}$ ion soil
sites, namely $^2$F$_{5/2,7/2}$ in the formulated Ca$_{14}$Al$_{10}$Zn$_6$O$_{35}$:Ce$^{3+}$ host materials [13], is established, in
relation to the literature study, as the double feature of trivalent cerium ions never found within
emission spectra. The excitation normally occurs among the highest ground-level which divides to 5d
level, meanwhile the emission occurs by the excitement level which is the lowest level towards the state of the two separating ground levels. Owing to this rare earth Ce\(^{3+}\) ion, extra 4f–5d absorption bands are observed among PLE spectrum, although the 5d–4f emissions seen in the photoluminescent emission spectra was standard dual band form Ce\(^{3+}\) ion 5d–4f emission spectrum that is largely dependent on the crystalline region. Frequently, the typical emission in Ce\(^{3+}\) ion at some particular lattice spot seen as doubling band by transitions detected owing to stable lowly 5d state of excitation at spin to orbit split at 4f as a ground state \((J=5/2, 7/2)\). Energy division between the two bands related to the common spin orbit splitting of spin-orbit \((2000 \text{ cm}^{-1})\). The maximum point of excitation is the energy difference of low 5d stage belonging to excitation of Ce\(^{3+}\) ions \((330 \text{ nm})\) within present Sr\(^{2+}\) host materials relative to Ce\(^{3+}\) ions \((6.118 \text{ eV})\); in this scenario, as stated in figure 03 and figure 04, the emissions spectrum is evidently since the very identical visible position. Hardly any emission band in the emission spectrum has been observed, indicating the trivalent cerium ion consists of one group of locations within host material. The nine-fold organization of Sr\(^{2+}\) was marked by C's evenness in an indistinguishable tri-capped prismatic geometry.

**Figure 3.** Excitation Spectra for Ca\(_{14}\)Al\(_{10}\)Zn\(_6\)O\(_{35}:\)Ce\(^{3+}\) phosphors, \(\lambda_{\text{em}}= 442 \text{ nm}\).

**Figure 4.** Emission spectra for Ca\(_{14}\)Al\(_{10}\)Zn\(_6\)O\(_{35}:\)Ce\(^{3+}\) phosphor \(\lambda_{\text{ex}}=330 \text{ nm}\) and correlation among Emission Intensity and Concentration in Ca\(_{14}\)Al\(_{10}\)Zn\(_6\)O\(_{35}:\) Ce\(^{3+}\) phosphor
A series of $\text{Ca}_{14}\text{Al}_{10}\text{Zn}_6\text{O}_{35} \cdot \text{Ce}^{3+}$ releases blue phosphors at various concentrations belonging to $\text{Ce}^{3+}$ viz. one mole each. Effect of the rare earth doped $\text{Ce}^{3+}$'s concentration over emission rate in formulated $\text{Ca}_{14}\text{Al}_{10}\text{Zn}_6\text{O}_{35} \cdot \text{Ce}^{3+}$ phosphor was measured at 10 mol %. Since it is important to examine the association between the concentrations in $\text{Ce}^{3+}$ ions also the emissions strength within $\text{Ca}_{14}\text{Al}_{10}\text{Zn}_6\text{O}_{35} \cdot \text{Ce}^{3+}$ phosphor precision identified. We visualize the excessive reference samples for each concentration in a graphical format. In the respective table 1, we describe the different concentrations of $\text{Ce}^{3+}$ with the strength of the emissions.

**Table 1.** Emission intensities respect to concentration in $\text{Ca}_{14}\text{Al}_{10}\text{Zn}_6\text{O}_{35}$ Blue emitting Phosphor

| S.N. | Conc. of $\text{Ce}^{3+}$ in $\text{Ca}_{14}\text{Al}_{10}\text{Zn}_6\text{O}_{35}$ phosphor | Emission intensity (a.u.) |
|------|---------------------------------------------------------------------------------|--------------------------|
| 1    | 1 mol%                                                                           | 69.602                   |
| 2    | 2 mol%                                                                           | 83.190                   |
| 3    | 5 mol%                                                                           | 120.163                  |
| 4    | 10 mol%                                                                          | 216.295                  |

With small concentrations in $\text{Ce}^{3+}$ ions, specifically (concentrations less than 2 mol. per cent), bright blue emission peak for the luminescence range is reached, however the emission intensity is determined to be mild, and as the artificial concentration of $\text{Ce}^{3+}$ ions is increased, then emission concentration further increased [14–15] also in summary, highest values is 10 mol. percent.

![Figure 5](image.png)

**Figure 5.** Effects of concentration of dopant–$\text{Ce}^{3+}$ on emission intensity of $\text{Ca}_{14}\text{Al}_{10}\text{Zn}_6\text{O}_{35} \cdot \text{Ce}^{3+}$ Phosphor

When ever we see instances of 10 mole percent of $\text{Ce}^{3+}$ concentration, the emission frequency being 216,295 nm, which is the maximum strength and also the lowest degree of emission intensity at 69,602 nm for 1 mole percent of $\text{Ce}^{3+}$ concentrations. It is then believed that there has been little change in the max value of the emission spectra.

**3.4 Chromatic properties of $\text{Ca}_{14}\text{Al}_{10}\text{Zn}_6\text{O}_{35} \cdot \text{Ce}^{3+}$ phosphor**

Here we test the chromaticity coordinates shown by the $\text{Ce}^{3+}$ emission spectra. The aid of the CIE diagram, it's indeed simple to follow that the $\text{Ca}_{14}\text{Al}_{10}\text{Zn}_6\text{O}_{35} \cdot \text{Ce}^{3+}$ phosphor is much similar to CIE
diagram, who indicates full colour clarity of the ready phosphors content. The CIE chromaticity description of Ca$_{14}$Al$_{10}$Zn$_6$O$_{35}$:Ce$^{3+}$ blue phosphor emission contained in the blue area (C$\chi$ = 0.228 C$\nu$ = 0.040) phosphor is as well shown inside the blue field within Figure 6. Mostly as product of emission as well as excitation method observed by connecting such points in triangle configuration, the go-between device can produce white light in an actual figure of formulated inorganic blue phosphors emitting.

![CIE chromatic-diagram for Ca$_{14}$Al$_{10}$Zn$_6$O$_{35}$:Ce$^{3+}$ phosphor.](image)

**Figure 6.** CIE chromatic-diagram for Ca$_{14}$Al$_{10}$Zn$_6$O$_{35}$:Ce$^{3+}$ phosphor.

4. Conclusion

The photoluminescence properties of the blue-emitting Ca$_{14}$Al$_{10}$Zn$_6$O$_{35}$:Ce$^{3+}$ phosphors at the very visible UV level reveal an emission band at 442 nm for the 330 nm excitation bands. Due to the extreme corresponding energy point, the $^{3}d_{25/2}$ to $^{3}d_{27/2}$ relativistic pressures variability is due to conceit and enhanced crystallographic field splitting. X-ray powder diffraction-pattern of Ca$_{14}$Al$_{10}$Zn$_6$O$_{35}$:Ce$^{3+}$, phosphor is indicative of good crystalline nature. SEM analysis showed micron phosphor morphology cut down to a few microns. As such, the results demonstrate that prepared phosphorus can be applied in blue for the phosphorus lamp.

5. References

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