Photoluminescence studies and synthesis of KSrPO₄:Ce³⁺, Eu³⁺ blue and orange-red emitting phosphor

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Abstract. The growing need for leftover fuels and the ecological effects of their use was intended to give life to the traditionally extended global superpower infrastructure. Conventional, reliable fluorescent and incandescent lamps emit energy in the form of either heat or gas discharge. Both principles are strongly owing to the greater energy fluctuations that arise related to higher temperatures with the greater shifts of Stokes concerned. Within this work, we recorded sulphate-based blue & Orange-red emitting phosphors for lamp industry applications prepared using updated wet chemical synthesis methods, because the production of superb materials with high and stable fluorescent and luminescent properties is necessary to achieve high emission and fine clarity in the innovation of display systems. Morphological and structural tests and validation of phase and quality were conducted using XRD and SEM. The photoluminescence emission spectra of KSrPO₄:Ce³⁺, Eu³⁺ phosphors show a blue emission band centered at 440 nm and a orange-red emission band centered at 593 nm and 618 nm. Typically, the structure of the Ce³⁺ ion in the ground state is split into two levels such as 2F⁵/₂ and 2F⁷/₂, while the ⁵d₁ excited configuration is divided by the crystal playing field into 2 and 5 elements.

1. Introduction
Currently, phosphor-converted white light-emitting diodes (w–LEDs) have been attracted worldwide attention as a new source for the solid-state lighting to next generation due to their special advantages such as long lifetimes, luminous efficiency, absence of mercury, low energy consumption, weak environmental impact, excellent chemical as well as physical stability, availability of final products in different sizes, and so on [1, 2]. A lot of studies have been investigating different luminescent materials to help the growth of suitable phosphors. Phosphors are also useful for producing white light when they are excited by blue or near-ultraviolet (NUV) lights (300–420 nm). It is very important to choose the right compound materials and assure they have outstanding physical and chemical stability for obtaining phosphors with highly proficient emissions.
Such materials are recombined with higher light capitulate, constructive emission wavelength, quicker fluorescence breakdown and temperature tolerance, rendering them desirable for use in high energy physics detectors [3] and even in medical imaging [4]. Thus, with the help of excellent luminescence properties, inorganic materials activated with Ce\(^{3+}\) ions are used in the lighting industry, detectors with ionizing radiation display systems [8-9]. A sample ion is therefore considered to measure the 5d energies of another rare earth ion in the similar host lattice material trivalent cerium ion [5]. Thus the study of spectroscopic properties of Ce\(^{3+}\) ion in different host material is essential for either actual applications or fundamental science. Wet chemical process is not yet another synthesis procedure recognized as a wet-chemical synthesis method but does not involve constant heating and calcinations. Starting up with the preparation of strontium nitrate, potassium nitrate, potassium phosphate with dual distillation water and cerium nitrate using the principle of propellant chemistry [6-7].

2. Experimental

The method of wet chemical synthesis was carried out roughly at a temperature of 100°C employing oven and with the aid of Merck analytical grade inorganic materials such as given below, KNO\(_3\) (99.99 percent Merck purity), Sr(NO\(_3\))\(_2\) (99.99 percent Merck purity), KPO\(_4\) (99.99 percent Merck purity), double distillation water and Cerium Nitrate (Ce(NO\(_3\))\(_3\), REI 99.9 percent) and Eu\(^{3+}\). The concentration of Ce\(^{3+}\) ranges by 1-10 mol percent and Eu\(^{3+}\) ranges from 0.1 to 2 mol %.

All the ingredients were arranged as per the stoichiometric ratio in the beaker with double distillation water and then lead to the stirring phase with the aid of the magnetic stirrer and then held the homogeneous mixture in oven, the temperature of which was sustained at 100 °C for 24 hours and at the end a pasty solution was formed, wherein the solution was then moved to the silica crucible, and retained inside the muffle furnace, that was maintained at a low temperature of around 100 °C. Foamy powder with flame was developed and the powder was extracted and thereby examined for emission and excitation spectra for photoluminescent evaluation.

3. Results and discussion

3.1 X-ray diffraction study

The preparation of the powder compound was defined for the analysis of its phase purity and crystallinity by powder X-ray diffraction (XRD) using the PAN Analytical X’pert Pro diffractometer XRD for the investigation of the XRD pattern of the prepared powder compound was validated using Cu-K\(_\alpha\) radiation (1.54060 nm) with a scanning stage time of 10,377 s with a continuous scan form. This KSrPO\(_4\):Ce\(^{3+}\) ion was prepared with respect to the normal JCPDS data source phosphor and found to be in good conformity with JCPDS data source file no.087-1854. The XRD level of the KSrPO\(_4\) compound is like as follow. The XRD-pattern indicates that phosphor has a strong crystalline nature. The X-ray diffraction pattern of the KSrPO\(_4\) compound as seen in the following figure 1. The material is heated up to 500°C at a steady temperature of 20°C in the argon atmosphere.
3.2 Scanning electron microscopic study of KSrPO₄ phosphor

The surface morphology analysis S.E.M. and the crystalline dimensions of the synthesized phosphor powder have been investigated. A wet chemical synthesis method conducted out by a heating reaction. This demonstrates that the wet chemical method of mixtures was quite well taken place. The characteristic morphological images are seen in figure 2, for KSrPO₄, consequently prepared phosphor materials. It is easily shown that the size of the crystalline micrographs ranges from a few microns to a range of tens of microns. The crystals include intelligent surface morphological representations and involve crystalline grains. Particles have foam-like composition developed from heavily agglomerated crystals. The normal crystalline scale is in the sub-micrometer range as seen in the SEM micrographic images; the crystalline sizes are exactly the same for all the prepared formulations.
3.3 Photoluminescence studies of KSrPO₄:Ce³⁺ blue emitting phosphor

Figure 3 and 4 shows photoluminescent excitation and emission spectra of KSrPO₄:Ce³⁺ phosphors displaying a broad absorption band in the range of 280 to 380 nm owing to the 4f–5d transformation of Ce³⁺ ions peaking at 329 nm. Photoluminescent emission spectra of KSrPO₄:Ce³⁺ phosphors as seen in figure 4 exhibit a blue emission band centered at 440 nm. Normally, the structure of Ce³⁺ ion in the ground state is split into 2 levels such as, 2F₅/₂ and 2F₇/₂, while the 3d excited configuration is divided by a crystal playing area of between 2 and 5 elements. Within this research work, the emission spectra of the ready samples exhibit a large blue emission band in the range of 400-650 nm at a maximum of 440 nm. In compliance with the literature analysis [8-9-10], the transition of the electron from the excited state of 2D₃ to the Ce³⁺ ion ground states such as, 2F₅/₂, 2F₇/₂ in the formulated KSrPO₄:Ce³⁺ host materials is known, the double feature of trivalent cerium ion never detected in the emission spectra. This photoluminescent emission spectrum arising from the spectral convergence of the various emission peaks associated with trivalent cerium ions have been replaced by five Sr sites in the T segment. As a result, there are multiple 4f–5d absorption bands in the PLE spectra for Ce³⁺, whereas the 5d-4f emission found in the photoluminescent emission spectrum is a typical double-band profile [11] based strongly on the crystallographic field. Ce³⁺ ion emission is mostly in the ultraviolet or blue spectral region, but it is moved to the green to the yellow zone (e.g. Y₃Al₅O₁₂:Ce³⁺), through the modulation of the crystallographic environment.

![Figure 3. Excitation spectra for KSrPO₄:Ce³⁺, λₑ𝐦.:-440 nm.](image_url)

Often, the characteristic emission of trivalent cerium ions at a particular lattice site occurs as doubling bands with transitions detected attributable to the relaxed low 5d excitation at 2F₁ (J=5/2,7/2) spin–orbit splitting 4f ground state. The energy separation of the two bands referring to the typical spin–orbit splitting of the 4f ground state (2000 cm⁻¹). The height of excitation, represented by the energy gap of the lowest 5d degree of excitation of trivalent cerium ion (329 nm) in the existing Sr²⁺ host material relative to the free trivalent cerium ion (6.118 eV) in the existing situation as description in figure 4. The emission spectra are distinctly from the same detectable location. Almost no emission band has been found in the
emission spectrum suggesting that trivalent cerium ion holds one group of locations in the host material [12].

![Emission spectra graph](image)

**Figure 4.** Emission spectra for KSrPO₄:Ce³⁺, λ<sub>ex</sub>: 329 nm.

Hence KSrPO₄:Ce³⁺ between blue emission is capable of finding useful uses as a blue emitting lamp phosphor. The substances KSrPO₄:Ce³⁺ were synthesised by updated wet chemical synthesis process and triggered by alkaline earth Ce³⁺ ion, varying from 1 to 10 mol percent with reference to corresponding source content. Crest emission wavelengths of processed fluoride-based aluminates relative to compounds produced at high temperature [13-14] are summarized by emission spectrum graphs. It will be examined that our prepared KSrPO₄:Ce³⁺ blue emitting phosphors emits a mild blue change in emission spectra with commercially available phosphors and has prospective applications for the blue lamp lighting industry.

### 3.4 Photoluminescence studies of KSrPO₄: Eu³⁺ Orange-Red emitting phosphor

Figure 5 explains the excitation spectrum of the KSrPO₄:Eu³⁺ phosphor monitored at 618 nm. The excitation spectrum shows the characteristic bands that were located at 370 nm because of intra configurational 4f–4f transitions of Eu³⁺ ions. Figure 6 demonstrate the emission spectrum of KSrPO₄:Eu³⁺ phosphors. Emission spectra shows two emission peaks located at about 593 nm,618 nm which was assigned because of transitions ²D<sub>0</sub>–²F₁ and ²D<sub>0</sub>–²F₂ respectively. The maximum emission intensity was noted at 618 nm, recommended that the Eu³⁺ ions engaged a middle of regularity in the KSrPO₄ host.
Figure 5. Excitation spectra for KSrPO$_4$:Eu$^{3+}$ phosphor.

It was noted that the as emission intensity improved with increasing Eu$^{3+}$ concentration and maximum emission intensity observed at 1 mol%. So, the photoluminescence results obtained concluded that the prepared phosphor may have possible applications in the area of solid-state lighting.

Figure 6. Emission spectra for KSrPO$_4$:Eu$^{3+}$, $\lambda_{ex}$: 370 nm.
3.5 Chromatic properties of KSrPO$_4$:Ce$^{3+}$ and Eu$^{3+}$ phosphor

We assume that when Ce$^{3+}$ ion is involved with the host lattice, the amount of energy may be transferred to the activator ion, arising from the distinctive special emission peak of these activator ions. [3-15] It is a well-known reality that the result obtained from the luminescence properties of prepared inorganic phosphors in powder form depending on the concentration of activator ion, hence recognition of doping concentration is necessary [14-15]. Considering the emission spectrum of Ce$^{3+}$ which was situated in the blue zone, the luminescent characteristics of KSrPO$_4$:Ce$^{3+}$ blue emitting phosphor were selected for further examination and characterization, and the total emission of color was achieved. Here we evaluate the chromaticity coordinate indexed by the Ce$^{3+}$ emission spectra.

![Figure 7. CIE chromatic diagram for KSrPO$_4$:Ce$^{3+}$ phosphor.](image)

Usually lighting means colors that apply to lighting under chromatic color coordinate conditions that recognize the human visualization scheme using 03 major colors: that is blue, red and green [16-14]. CIE chromaticity schematic KSrPO$_4$:Ce$^{3+}$ blue phosphor emitting diagram seen in Figure 7. The color coordinates of KSrPO$_4$:Ce$^{3+}$ phosphor found in the blue region ($C_x =0.236$, $C_y =0.034$) Phosphor while in case of Eu$^{3+}$ phosphor found in the orange –red region with the aid of the CIE diagram, it is simple to understand that the KSrPO$_4$:Ce$^{3+}$ and Eu$^{3+}$ phosphor are quite similar to the CIE graph frame, which is easy to show the highest color transparency of the prepared phosphor material. As a consequence of the emission and excitation process found by connecting these points in the tri-angle structure jointly with white light (0.31 and 0.32), the go-between arrangement with a exacting percentage of prepared inorganic blue emitting phosphor [17-18]. Due to the growing consequence of Ce$^{3+}$ activated KSrPO$_4$ with desirable blue and orange –red emitting optical properties which make up the prepared inorganic blue emitting phosphor, it has become an outstanding prospective applicant for industrial blue emitting phosphor applications.
4. Conclusion
In this research work, KSrPO₄:Ce³⁺ and Eu³⁺ phosphor prepared using a wet chemical synthesis technique. High resolution electron micrographic scanning analysis reveals the presence of various tiny particles within the plate as well as normal crystalline grains in the micron to submicron scale. The emission bands obtained because of the 4f⁶5d¹→4f⁷ transformation of Ce³⁺ ion, which belongs to the deep blue spectrum region excited at 329 nm, near uv-excitation and in case of Eu³⁺ ion emission spectra shows two emission peaks located at about 593 nm, 618 nm which was assigned because of transitions 3D⁰→F₁ and 3D⁰→F₂ respectively. Chromaticity coordinates specify the details location of the color rendering index with the help of emission spectra analysis. As a result, we reached the conclusion that our prepared inorganic phosphores have a prospective application for the Blue and orange-red Lighting Lamp Industry applications.

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