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SYNTHESIS AND CHARACTERIZATION OF PHOSPHATE-BASED PHOSPHORS: REVIEW

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***Abstract*:** Worldwide commercial interest in the production of phosphate-based phosphors is reflected in the widespread use of the white light emitting device. Phosphors are luminescent materials when it is excited by external energy sources photons are emitted. This article reviews some developed techniques for producing phosphate-based phosphors such as the solid-state reaction method, precipitation method, low-temperature solution combustion method, wet chemical synthesis method, etc., and also discussed their characterization techniques. Recently, rare earth-activated phosphate-based phosphors have made great attention due to their excellent ability to host activator ions in their lattice, higher quantum fields, low toxicity, and higher chemical and thermal stability, and are mainly used for optoelectronic and biomedical applications.

Keywords: Cathodoluminescence, ultra-violet, solid-state reaction method.

1. INTRODUCTION

Luminescent materials are one of the phosphors, and phosphor means “light bearer”. Generally, a phosphor is a solid that can convert some sources of energy into electromagnetic radiation over and above thermal radiation [1]. Phosphors are a chemical compound that produces luminescence. When it is bombarded with an external energy source it will emit radiation. The researcher has given more attention to alkaline earth phosphate phosphors as due to its advancement in synthesis and characterization this material has many advantages in solid-state lighting over fluorescent and incandescent lights. All over the world phosphors are essential for LED technologies and converting the light emitted by a blue or UV chip into white light. Rare−earth doped phosphors have outstanding physical and chemical properties such as good chemical and thermal stability, high durability, efficiency, and environmentally friendly characteristics [2-4]. It is observed that phosphate-based phosphor has attractive thermal and hydrolytic strengths and has a wide range of applications, in optoelectronic devices, solid−state lasers, illumination light sources, and biomedical applications [5-6]. The efficiency of phosphor can be increased by co-doping with suitable sensitizer ions. As mentioned in the literature, the efficiency of the luminescent phosphor can be improved by adding a small amount of co-doping of the sensitizers [7].

Among all the rare earth elements, the most commonly used activators are Eu and Dy, which produces sharp emissions in the visible blue–a green–red region of the electromagnetic spectrum [8–10]. Recently, lanthanide-doped inorganic phosphors have become a significant role in solid-state lighting sources [11], light-emitting phosphors or illumination [12-13], optical devices [14], fiber-optics communication applications [15], sensors-based devices [16], non-linear optical applications [17]. Due to utilization in different fields and luminous decay or long lifespan, these phosphates receive great interest from researchers. Thus, they have potential applications in light-emitting diodes (LEDs) [18-19]. In the present study, we have reviewed the synthesis technique of phosphate-based phosphor synthesis and discussed the structural and optical properties of the phosphors.

2. STRUCTURAL AND LUMINESCENCE PROPERTIES OF PHOSPHATE-BASED PHOSPHORS

Different research groups have reported rare earth phosphates prepared by different methods such as high-temperature solid-state reaction technique, sol-gel method, wet chemical method, precipitation technique, and hydrothermal synthesis [20- 27]. Rare earth-doped phosphates were synthesized by the precipitation method and reported that the stable condition of the synthesized phosphate obtained an amorphous state at 723K and also discussed the thermal behavior of phosphate that is dependent on the calcination temperatures [28]. Microcrystalline rare earth phosphate $RePO_4$ (Re = La, Ce, Nd, Eu, Y) also reported by Guo et al. synthesized through the sol-gel technique [29].

Bamzai et al studied the synthesis and characterization of Pure and dysprosium-doped yttrium phosphate phosphor. It is reported that pure yttrium phosphate is found in platelet form like crystal, and is found in floral growth form on the condensed gel. The X-ray diffraction pattern revealed that both yttrium phosphate and doped yttrium phosphate have a tetragonal structure with lattice parameter $a = b = 6.8832$ A, ˚ c = 6.0208 A and ˚ $a = b = 6.9987$ A, ˚ $c = 6.0142$ A. Fourier transformed infrared investigation confirm the presence of water molecules, along with the orthophosphate functional group and metallic ion group. The frequency bands are observed in the region between 3829.4 to 2424.2 cm^{-1} which is ascribed to the presence of water molecules. The thermal studies disclose that pure yttrium phosphate is less stable as compared to dysprosium-doped yttrium phosphate and during the decomposition process yttrium phosphate goes through three different stages and with the release of H_2O, P_2O_5, and O_2 final product yttrium monoxide is obtained, while for dysprosium doped yttrium phosphate, a final product obtained was yttrium pyrophosphate was obtained with a release of H_2O, PO_3, and O_2 gases [30].

3. LUMINESCENCE PROPERTIES OF GADOLINIUM PHOSPHATE

Alkali metal ion co-doped $GdPO_4$ phosphors were investigated by Halppa et al. The X-ray Rietveld refinement method confirmed that crystallized material is the monazite phase with space group (P_{121}/n_1, No.14). The photoluminescence (PL) studies disclosed that on doping with Eu^{3+} ion the intensity of magnetic dipole transition ($^5D_0 \rightarrow {}^7F_1$) at 581 nm is dominated over dominates the electric dipole transition ($^5D_0 \rightarrow {}^7F_2$) at 620 nm. This suggested that Eu^{3+} ions are situated at high symmetry local sites through an inversion center in the $GdPO_4$ lattice. Also, the luminescence intensity of Eu^{3+}-activated $GdPO_4$ phosphor can be enhanced due to co-doping with alkali metal ions (Li^+, Na^+, and K^+). Thus, these phosphors have a higher lifetime, better quantum efficiency, and excellent chromaticity with high color purity values and can be promising material optoelectronic and biomedical field applications [31].

The highly uniform and well-dispersed hexagonal phase GdPO4 nanorods were synthesized by hydrothermal method. At heating above 800°C, $GdPO_4$ nanocrystals transferred to the monoclinic phase. Upon excitation at 368 nm, the integrated emission intensity of the $GdPO_4$:0.07 Tb^{3+} nanocrystal was nearly 2.62 times stronger than that of $GdPO_4 \cdot H_2O$:0.07 Tb^{3+}. The color tone of the samples can be changed from green and warm white to red by codoping the Tb^{3+} and Eu^{3+} ions into the $GdPO_4$ host and also by adjusting Eu^{3+} doping concentrations, which might be due to the energy transfer mechanism from Tb^{3+} to Eu^{3+} ions. The energy transfer mechanism from Tb^{3+} to Eu^{3+} was due to an electric quadrupole interaction, and when the concentration unit of Eu^{3+} was 12 mol% the energy transfer efficiency reached around 96.1%. Therefore, this material is more suitable for warm-white display fields [32]. Sm-activated $GdPO_4$ nano phosphors have been reported by Ouertania et al. The concentration of Sm^{3+} has been varied from 1 to 5% and prepared through the combustion method. The luminescence properties of the phosphor have been studied which was based on photoluminescence excitation and emission spectra, and also on decay curves. The photoluminescence excitation spectra show a large number of characteristics peak due to the charge transfer state and 4–4 f electronic transitions of Sm^{3+} and Gd^{3+} ions. The decay time curves have double exponential profiles and the registered spectra as well as decay times depend upon the excitation wavelength and the Sm3+ concentration. The $GdPO_4$:Sm^{3+} phosphor may be a suitable candidate for solid-state displays and photonic devices [33].

4. CONCLUSION

This review reported an overview of the phosphate-based phosphors and different synthesis methods has been adopted in the literature for their preparation. The crystal structure of the phosphate forms can be exhibited in various forms namely, hexagonal, tetragonal, and monoclinic phases, depending on the synthesis conditions and methods. Several research works have been done to improve the efficiency of the phosphors, either by changing the synthesis technique or by the use of different activators or sensitizers. The optical properties of the phosphate indicate that these materials have a wide range of applications in the field of display, illumination, fiber-optics communication applications, photonic devices, sensors-based devices, and non-linear optical applications.

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