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A Brief Synthesis Methods And Luminescence Development Of Rare Earth Activated Phosphate Phosphor Materials

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Abstract

Rare-earth activated phosphors are capable of producing luminescent materials which are developed to overcoming the drawback of traditional based phosphors. Most changes happened in efficiencies of lighting for colors in the novel area research. This article presents a concise overview of the synthesis methods employed for the preparation of rare earth-activated phosphate phosphors and highlights the key factors influencing their luminescence properties. Understanding these synthesis techniques is crucial for tailoring the properties of these phosphors to meet specific application requirements and optimizing their performance.

Key words: Phosphate Phosphors, Rare-earth and Luminescence

Introduction:

Luminescence, which is considered as a form of cool body radiation, is the term used for the sort of light emission that occurs when a material is properly excited. Here both fluorescence and phosphorescence are common categories for luminescence. Fluorescence refers to the radiation that arises from the transition from a singlet to a single state, but phosphorescence was the outcome that results from the triplet to a triplet state transition. Broadly speaking, the output of light in fluorescence ends when the excitation supply is removed, whereas it continues in phosphorescence. The processes may also be confirmed using lifetime (τ) evaluation, wherein the lifetime (τ) in fluorescence is less than 10 ms, but in phosphorescence, it exceeds 0.10 s. Our ability to see our surroundings is dependent on the visible portion of solar energy. Phosphors are the materials that produce these emissions [1–2].

In recent years, rare earth-activated phosphate phosphors have garnered significant attention due to their unique luminescent properties and diverse applications in various fields such as optoelectronics, lighting, displays, and medical imaging. These phosphors, doped with rare earth ions, exhibit remarkable luminescence characteristics, including high quantum efficiency, tunable emission spectra, and excellent thermal stability, making them highly desirable for use in advanced technologies.

Furthermore, this review delves into the luminescence development of rare earth-activated phosphate phosphors, focusing on the role of various factors such as host matrix composition, doping concentration, crystal structure, and thermal treatment conditions. The interaction between the rare earth ions and the host lattice profoundly influences the emission properties, including emission wavelength, intensity, and decay kinetics. The inclusion of other impurities, such as sensitizers and surface modifiers, also had a significant impact on the photoluminescence intensity of rare earth (RE) ions, which amongst other ions, produce strong, short band width and crisp lines of diverse emissions stretching from ultraviolet–visible to near infrared areas [3-4].

Materials & Synthesis Methods:

We have discussed several kinds of methods and materials which have previously generated. Some of them are listed in the Table 1.

Table: 1 Phosphate-based rare earth luminescent substances

Year	Synthesized Phosphate Phosphors	Starting precursors	Synthesis Methods – Emission color	Excitations	Emissions	Reference
2017	KSr(PO4): Tb^{3+}, Pr^{3+}, Ce^{3+}, Dy^{3+}, Ce^{3+}/Pr^{3+}	$K(NO_3)_2$, $Sr(NO_3)_2$, $NH_4H_2(PO_4)$, $(NH_4)_2Ce(NO_3)_6$, Tb_2O_3, Pr_6O_{11} ,and Dy_2O_3	wet chemical routes	227nm: Tb^{3+} 300-500nm: Pr^{3+} 309 nm: Ce^{3+} 348nm: Dy^{3+}	546 nm: Tb^{3+} 600 nm: Pr^{3+} 320 - 450 nm: Ce^{3+} 300 - 400 nm: Dy^{3+}	5
2018	$NaSrPO_4:Tm^{3+}$	Na_2CO_3 , $SrCO_3$, $NH_4H_2PO_4$ and Tm_2O_3	solid-state sintering – blue colour	357nm	452nm	6
2019	Pyrophosphate $Li_2BaP_2O_7$: Er^{3+}	(Li_2CO_3), $(BaCO_3)$, Er_2O_3 and $NH_4H_2PO_4$	classic ceramic method – green emission	400nm	545nm	7
2019	$Ba_2Mg(PO_4)_2:Eu^{3+}$	$Mg(NO_3)_2.6H_2O$, $Ba(NO_3)_2$, $NH_4H_2PO_4$ and Eu_2O_3	wet chemical method-orange - red emission light	396nm	592nm	8
2020	$CaSr_2(PO_4)_2$: Eu^{3+}, Dy^{3+}	$CaCO_3$,$2SrCO_3$, $2NH_4H_2$ (PO_4), Eu_2O_3 and Dy_2O_3	solid-State diffusion method –orange - red and blue –yellow colors	395nm- Eu^{3+}, 350nm-Dy^{3+}	Eu^{3+} = (593nm(Orange)& 615nm (Red)), Dy^{3+}=(481nm(Blue) & 572 nm)	9
2021	$Na_6CaP_2O_9$: Eu^{3+}	Na_2CO_3, $CaCO_3$, $NH_4H_2PO_4$ and Eu_2O_3	solid – state reaction method	393nm	612nm	10
2022	$MgZr_4(PO_4)_6$-Er^{3+}	$MgN_2O_6{\cdot}6H_2O$, $NH_4H_2PO_4$, $ZrOC_{l2}{\cdot}8H_2O$, $Er(NO_3)_3{\cdot}5H_2O$, 150 ml deionised water, $ZrOC_{l2}{\cdot}8H_2O$ aqueous solution	sol–gel Technique	980 nm	1533 nm	11

Recognized and scrutinized substances:

A wide variety of host materials are used as luminescent compounds, but when it comes to persistent luminescence, the number of known hosts is relatively low. The materials known as phosphate phosphors have been the focus of much study on these phenomena.

The rare earth activated (RE=Pr^{3+}, Tb^{3+}, Ce^{3+}, Dy^{3+}, Ce^{3+}/Pr^{3+}) $KSr(PO_4)$ nanocrystalline phosphors were synthesized at low temperature, concentrated on Phase purity, surface morphology, crystallite size and structure of materials has been characterized by XRD, SEM and HRTEM techniques. The wet chemical routes are well suited technique to prepare spherical nanoparticles. This material exhibit excellent luminescence properties in visible to NIR range under UV excitation wavelength due to f-f and d-f transition of rare earth ions. The prepared phosphate based host is useful to increase the light conversion efficiency of silicon solar cell by V. B. Pawade et al [5]

The Tm^{3+} ion doped $NaSrPO_4$ phosphor were synthesized to develop new blue-emitting light for WLEDs and concentrated on micro morphology and luminescence properties like PL emission spectra and CIE color coordinates confirm prepared phosphate material is suitable by solid state technique to emit higher color purity with 95% of blue light with dipole-dipole interaction mechanism by Yang Li et al [6]

The different concentration of Er^{3+} doped $Li_2BaP_2O_7$ was synthesized by classic ceramic method and concentrated on structural, vibrational, optical characterizations and Judd–Ofelt parameters found from absorption spectra. The luminescence intensity enhanced until to doping concentration 3% with green-emission under 400nm excitation and emission quantum efficiency 42% under the 375 nm excitation with decay time of 0.083 ms. The exhibited results suggest that the $Li_2BaP_2O_7$: Er^{3+} can be used as a novel green phosphor by M. Beltaif et al [7]

The $Ba_2Mg(PO_4)_2$:Eu^{3+} were synthesized by the method of wet chemical reaction. By SEM describes irregular morphology and irregular shape of particle and size varied with 10 - 50 micron. PL gives highest excitation peak at 396 nm in the range of 345 to 396 nm peaks and also exhibited maximum emission peak at 615 nm in the peaks of 592 nm and 615 nm. The CIE coordinates found to be (0.586, 0.412) for the 592 nm

and (0.680, 0.319) for the 615 nm wavelengths and were situated close to the edge of CIE diagram, indicating the high color purity of these phosphors. The obtained CIE color coordinates, PL results, and SEM investigations suggested that the prepared phosphor would be suitable for solid-state lighting applications by S.K. Ramteke et al [8]

Eu^{3+} and Dy^{3+} activated $CaSr_2(PO_4)_2$ phosphors were synthesized by solid state diffusion method. PL describes Eu^{3+} doped material monitored at395nm and exhibit orange (593 nm) and red (615 nm) emission peaks and Dy^{3+} material monitored at 350 nm and exhibit blue (481nm) and yellow (572 nm) emission peaks respectively. CIE chromaticity shows high color purity, excellent chromaticity coordinates and emission band presence in the visible spectrum for lighting applications by Y. R. Parauha et al [9]

$Na_6CaP_2O_9$: Eu^{3+} phosphors were synthesized by conventional solid state reaction method and found the applicability of the material in optoelectronic devices. The band gap of 3.96 eV– 4.21 eV and excitation charge transfer band (225-300 nm) with some sharp peaks from 300-400 nm obtained due to 4f–4f transitions of europium ion phosphors. It exhibit optimum orange-red emission at the excitation of 393nm. From a detailed analysis of the emission spectrum, the phenomenological Judd- Ofelt intensity parameters were calculated and then were used to predict the various radiative properties of the phosphor.The discovered radiative characteristics validate the current matrix's applicability for photonic programmes, including laser light and optical boosters. It exhibit excellent thermal stability, for instance, the PL intensity at 423 K was 86.3 % of the initial value at room temperature and the thermal activation energy is Ea = 0.132 eV and good IQE (53.97 %). The calculated CIE coordinates (0.626, 0.372) of the sample is suitable phosphors like Y2O3: Eu3+ (0.62, 0.37). Therefore, the present phosphor can be used as an orange–red component material in the case of NUV based WLED’s by T. Krishnapriya et al [10]

The $MgZr_4(PO_4)_6$: Er^{3+} nano phosphors were synthesized showed single crystalline phase when enhance of doping concentration by TEM and further confirmed by XRD analysis. The Scherrer equation and W-H analysis gives the crystallite size and lattice strain. PL spectra give the strong emission intensity at 1533 nm under 980 nm excitation wavelengths. The decreasing in PL lifetime as the Er^{3+} doping concentration increases is attributed to concentration quenching effects and/or changes in local crystal field. PL properties

exhibited huge potential for lighting and optical amplifiers around 1533 nm wavelength by T. Choudhury et al [11]

Conclusion:

In summary, this paper provides a comprehensive overview of the synthesis methods discussed encompass the range of techniques, including solid-state sintering, classic ceramic method, wet chemical method and sol-gel method. Each method offers distinct advantages in terms of controlling particle size, morphology, crystalline and doping concentration, which directly impact the luminescence efficiency and spectral characteristics of the phosphors. This article highlighting their potential for advancing luminescent materials' design and functionality. By elucidating the intricate relationship between synthesis parameters and luminescence properties, researchers and technologists can unlock new opportunities for innovation in lighting, displays and other optoelectronic devices.

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