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Optimized photoluminescence in $NaCaPO_4$ phosphors by rare-earth tuning towards white light emission

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ABSTRACT

The study utilized a solid-state reaction technique to synthesize Dy-doped and Tb-doped $NaCaPO_4$ luminescent materials. Trivalent rare-earth-doped luminescent materials are known for their unique spectroscopic properties and their versatility in solid-state lighting and display systems. The FullProf Suite Software was used for phase pureness and crystal structural evaluations, confirming the formation of single-phase. Dy-doped materials exhibit two distinct transition bands in their photoluminescence (PL) emission spectra, while Tb-doped materials display four distinct emission bands. The temperature-dependent PL demonstrated exceptional thermal stability, while multipolar interactions enabled non-radiative energy transfer, leading to concentration quenching. The CIE color coordinate analysis reveals that trivalent rare-earth-doped phosphors possess excellent illuminating properties, making them suitable for solid-state lighting systems.

1. Introduction

Since the 19th century, the development of fluorescent lamps has spurred the exploration of new technologies and materials to meet the growing global lighting needs. The study of new inorganic luminescent substances for lighting applications has gained significant scientific interest due to their exceptional characteristics. After that time, energy has emerged as one of the most crucial assets globally, and the need for it in many sectors is expanding at a rapid rate all the time. Lighting is a vital aspect of commerce, residences, and businesses, yet it consumes an immense amount of energy [1–4]. Phosphors are fascinating substances for solid-state lighting (SSL) and medical research because of their enhanced luminescent effectiveness, chemical resilience, durability against heat, and extended operating lifespan. SSL-based white light emitting diodes (WLEDs) are acceptable options for both indoor and outdoor lighting, backlighting for display screens, and projections. WLEDs are polychromatic solid-state LEDs with minimal electrical consumption, long operating life, consistent light characteristics, and eco-friendliness widely used in the illumination sector. White light, produced by combining primary colors or complementary combinations, can conserve 70 percent of energy and be free of toxic aspects compared to conventional light sources [5–11].

The primary objective of this study is to yield lighting materials on a single phosphate host matrix that includes Dy and Tb rare-earth-ions because of their advantageous attributes. The study focuses on the doping of these ions at different concentrations in an orthophosphate host material having the general formula $X^{I}Y^{II}PO_4$ (where X^{I} is an alkali metal and Y^{II} is an alkaline earth metal). Several trivalent rare-earth-doped $X^{I}Y^{II}PO_4$ phosphors are being used in WLEDs owing to their enhanced luminosity [12–19], but $NaCaPO_4$ orthophosphate-based phosphors exhibit a promising option for future SSL applications due to its exceptional temperature and charge stability, as well as its strong UV absorption [20,21]. In the current manuscript, we have prepared $NaCaPO_4$ host samples incorporated with varied amounts of Dy and Tb rare-earth ions, utilizing a high-temperature reaction method, and investigated their comparative structural, microstructural, and temperature-dependent PL on these prepared materials.

2. Experimental methodology

2.1. Sample preparation

We have synthesized a series of polycrystalline samples of $NaCa_{1-x}PO_4$: $(Dy)_x$; $(Tb)_x$ with (x = 0.00 for host; x = 0.02, 0.03, 0.04, 0.05, 0.06 for Dy-doped and x = 0.01, 0.03, 0.05,0.07, 0.09 for Tb-doped) materials via a high-temperature reaction methodology. The basic ingredients for this study were taken from Sigma Aldrich, including $CaCO_3$ (99.90 %), Na_2CO_3 (99.5 %), $NH_2H_4PO_4$ (99.98 %), and rare earths such

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