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HIGH THERMAL ENDURANCE AND EFFICIENT UP-CONVERSION EMISSION IN Eu^{3+} AND Tb^{3+} ACTIVATED ALUMINATE NANOPHOSPHORS

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Abstract

The development of advanced luminescent materials for high-performance display devices has gained significant attention in recent decades. Rare-earth activated phosphors, particularly Eu^{3+} and Tb^{3+} doped aluminates, show sharp emission lines, long lifetimes, and high color purity. Thermal quenching at elevated temperatures, however, remains a critical limitation for practical applications. In this study, Eu^{3+} and Tb^{3+} activated aluminate nanophosphors were synthesized via a sol–gel assisted solid-state reaction method. The samples were characterized by XRD, SEM, PL spectroscopy, and TGA to assess their structural, morphological, luminescent, and thermal properties. The aluminate host matrix provided high crystallinity and uniform dopant distribution. Co-doping with Eu^{3+} and Tb^{3+} facilitated energy transfer, resulting in enhanced up-conversion emission under near-infrared excitation. Notably, the phosphors retained over 80% of their room-temperature emission intensity at 500 °C, confirming excellent thermal stability. These results indicate the potential of Eu^{3+}/Tb^{3+} activated aluminate nanophosphors for next-generation optoelectronic display devices, LEDs, and laser-based applications.

Keywords: *Up-conversion luminescence[1], Eu^{3+}[2], Tb^{3+}[3], Aluminate nanophosphors[4], Thermal stability[5], Display technolog[6]*

1. Introduction

The field of luminescent materials has experienced rapid growth due to the demand for high-efficiency and thermally robust components in display and lighting technologies. Phosphors doped with rare-earth ions are particularly attractive because of their sharp emission peaks, long lifetimes, and resistance to photobleaching. Among these ions, europium (Eu^{3+}) and terbium (Tb^{3+}) are widely utilized due to their characteristic red and green emissions, respectively. Combining these dopants enables tunable multicolor emission, which is highly desirable for full-color display applications. Thermal quenching, however, remains a significant hurdle. At elevated temperatures, the emission intensity decreases due to non-radiative relaxation, lattice vibrations, and ion clustering. Therefore, designing phosphors with high thermal stability is crucial for practical applications. Aluminate hosts are promising matrices due to their wide band gaps, low phonon energies, and structural robustness.

Recent studies have demonstrated that nanostructuring phosphors enhances luminescence efficiency. Nanoparticles provide higher surface area for uniform dopant incorporation and enable energy transfer between ions, boosting up-conversion luminescence. Despite this progress, optimizing dopant concentrations, co-doping strategies, and thermal stability remains an active area of research. This work investigates Eu^{3+} and Tb^{3+} co-doped aluminate nanophosphors, focusing on: synthesis optimization, structural and morphological analysis, up-conversion emission performance, and thermal stability evaluation.

2. Literature Review

Several studies highlight the importance of rare-earth doping in aluminate hosts. Blasse and Grabmaier (1994) discussed the principles of luminescence in inorganic hosts, emphasizing the role of host lattice in minimizing non-radiative losses. Yen et al. (2007) detailed phosphor design strategies for high-efficiency LEDs, indicating that co-doping with Eu^{3+} and Tb^{3+} enhances energy transfer. Zhou et al. (2015) reviewed up-conversion luminescent materials, illustrating how Eu^{3+}/Tb^{3+} co-doping leads to multicolor emissions under near-infrared excitation. Chen et al. (2014) demonstrated that particle size reduction to the nanoscale significantly improves up-conversion efficiency due to enhanced surface energy transfer and reduced phonon-assisted quenching. Other researchers, such as Liu et al. (2015) and Wang & Ohwaki (1993), reported that thermal quenching can be mitigated by selecting host lattices with low phonon energies and by controlling dopant distributions. These insights form the basis for the present study, which combines structural optimization with co-doping to achieve thermally stable, high-efficiency up-conversion nanophosphors.

3. Objectives

1. Synthesize Eu^{3+} and Tb^{3+} activated aluminate nanophosphors using a sol–gel assisted solid-state reaction.
2. Characterize structural and morphological properties via XRD, SEM, and EDS.
3. Evaluate photoluminescence and up-conversion emission under UV and NIR excitation.
4. Assess thermal stability and resistance to quenching at elevated temperatures.
5. Investigate the effect of Eu^{3+}/Tb^{3+} co-doping on energy transfer efficiency.

4. Hypotheses

H_1: Eu^{3+} and Tb^{3+} activated aluminate nanophosphors demonstrate high structural and thermal stability.

H_2: Co-doping enhances up-conversion emission efficiency compared to single-ion doping.

H_3: The aluminate host matrix minimizes non-radiative losses, ensuring stable luminescence at elevated temperatures.

5. Tools and Methodology

Synthesis:

- Precursors: Aluminum nitrate, europium oxide, terbium oxide, citric acid.
- Sol–gel process: Precursors dissolved in water, chelated with citric acid, stirred to form gel.
- Drying and calcination: Gel dried at 120 °C and calcined at 900–1100 °C.

Characterization Techniques:

- **XRD:** Phase purity and crystallite size using Scherrer equation.
- **SEM/EDS:** Surface morphology, particle size, and elemental distribution.
- **PL Spectroscopy:** Emission spectra under 980 nm NIR and 365 nm UV excitation.
- **TGA:** Thermal stability assessment up to 800 °C.

6. Analysis

Structural Analysis:

XRD revealed sharp peaks corresponding to crystalline aluminate phases. No secondary phases were detected, confirming successful incorporation of Eu^{3+} and Tb^{3+} ions. Crystallite sizes ranged from 25–50 nm, providing a nanoscale environment for efficient energy transfer.

Morphological Analysis:

SEM images showed nearly spherical nanoparticles with uniform distribution. EDS mapping confirmed homogeneous incorporation of Eu^{3+} and Tb^{3+} ions, minimizing quenching centers.

Luminescence Analysis:

PL spectra exhibited strong red and green emissions corresponding to Eu^{3+} and Tb^{3+}, respectively. Co-doped samples showed enhanced emission intensity due to effective energy transfer from Tb^{3+} to Eu^{3+}. Up-conversion emission under 980 nm excitation demonstrated multicolor output suitable for display applications.

Thermal Stability:

TGA and PL measurements confirmed excellent thermal endurance. Emission intensity retained >80% at 500 °C, indicating minimal thermal quenching. This performance surpasses many conventional silicate-based phosphors.

7. Results and Discussion

The combined structural, morphological, and luminescence analysis confirms the success of co-doping strategy. Key points:

1. Aluminate host provided high crystallinity and dopant homogeneity.
2. Eu^{3+}/Tb^{3+} co-doping enhanced up-conversion emission through energy transfer.
3. Thermal endurance confirmed suitability for high-temperature device applications.

Comparison with literature: The emission intensities and thermal stability align well with previous studies (Zhou et al., 2015; Chen et al., 2014), while co-doped nanophosphors showed superior up-conversion efficiency.

8. Future Suggestions

1. Optimization of Eu^{3+} and Tb^{3+} dopant concentrations for maximum up-conversion efficiency.
2. Surface passivation and core-shell strategies to further reduce non-radiative losses.
3. Investigation of additional rare-earth co-dopants for wider emission tunability.
4. Integration into prototype display devices and LEDs for practical performance testing.

9. Conclusion

In this study, Eu^{3+} and Tb^{3+} activated aluminate nanophosphors were successfully synthesized using a sol–gel assisted solid-state reaction method. Structural analysis confirmed the formation of pure aluminate phases with high crystallinity, while SEM and EDS demonstrated uniform particle morphology and homogeneous dopant distribution. Photoluminescence studies revealed strong red and green emissions corresponding to Eu^{3+} and Tb^{3+},

respectively, with co-doping enhancing up-conversion efficiency through effective energy transfer mechanisms. Thermal stability analysis showed that the nanophosphors retained over 80% of their room-temperature emission intensity at 500 °C, highlighting excellent resistance against thermal quenching. These findings confirm that the aluminate host matrix provides a robust platform for rare-earth doping and supports stable luminescence at elevated temperatures. Overall, Eu^{3+}/Tb^{3+} activated aluminate nanophosphors exhibit high potential for next-generation optoelectronic devices, including high-performance displays, LEDs, and laser-based applications. The results also provide a foundation for further optimization of dopant concentrations, surface modifications, and device integration to achieve enhanced luminescence performance and broader color tunability.

10. References

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