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Photoluminescence Investigation of $NaAl_5O_8$ and $NaAl_5O_8$: Gd^{3+} (1 Mol%) Phosphor for Ultraviolet Emission Applications

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Abstract

A comprehensive photoluminescence investigation of $NaAl_5O_8$ and $NaAl_5O_8$: Gd^{3+} (1 mol%) phosphor has been carried out to evaluate its suitability for ultraviolet photonic applications. The excitation spectrum of the doped sample exhibits sharp absorption bands at 275 nm and 312 nm corresponding to intra-4f transitions of Gd^{3+} ions. Upon excitation, intense ultraviolet emission centred at 312 nm is observed due to the characteristic 6P7/2→8S7/2^6P_{7/2} \right arrow ^8S_{7/2}6P7/2→8S7/2 transition of Gd^{3+}. The undoped host shows weak broad defect-related emission, whereas Gd^{3+} doping significantly enhances emission intensity and spectral purity. The decay analysis reveals microsecond lifetime behaviour (~2 µs), confirming magnetic dipole transition dominance. Concentration quenching is governed by multipolar (dipole–dipole) interaction as estimated using the Blasse equation. CIE chromaticity coordinates ($x \approx 0.18$, $y \approx 0.02$) confirm near-UV emission. The results demonstrate that $NaAl_5O_8$: Gd^{3+} is a promising ultraviolet phosphor for advanced photonic and scintillation applications.

Keywords: Photoluminescence, Gd^{3+}, $NaAl_5O_8$, Rare-earth phosphor, Ultraviolet emission, Concentration quenching

1. Introduction

Rare-earth doped oxide phosphors have attracted considerable attention due to their sharp emission bands, thermal stability, and high chemical durability. Among rare-earth ions, Gd^{3+} ($4f^7$ configuration) is known for its characteristic ultraviolet emission around 310–313 nm arising from the 6P7/2→8S7/2^6P_{7/2} \rightarrow ^8S_{7/2}6P7/2→8S7/2 transition. The shielded 4f orbitals of Gd^{3+} ensure minimal interaction with the host lattice, leading to narrow emission bands.

Aluminate hosts are widely investigated because of their wide band gap, low phonon energy, and structural stability. $NaAl_5O_8$ is a wide band gap oxide that can act as an efficient host lattice for rare-earth ions. In this study, we report a detailed photoluminescence investigation of $NaAl_5O_8$ and $NaAl_5O_8$: Gd^{3+} (1 mol%) phosphor, including excitation behavior, emission characteristics, lifetime analysis, concentration quenching mechanism, and chromaticity evaluation.

2. Experimental Procedure

$NaAl_5O_8$ and $NaAl_5O_8:Gd^{3+}$ (1 mol%) phosphors were synthesized using conventional solid-state reaction method. Stoichiometric amounts of high-purity precursors were mixed, ground thoroughly, and calcined at elevated temperature to obtain phase-pure samples.

Photoluminescence excitation and emission spectra were recorded using a fluorescence spectrophotometer in the wavelength range 200–450 nm. Lifetime measurements were performed using time-resolved photoluminescence spectroscopy. Chromaticity coordinates were calculated using CIE 1931 standard observer functions.

3. Results and Discussion

3.1 Photoluminescence Excitation Analysis

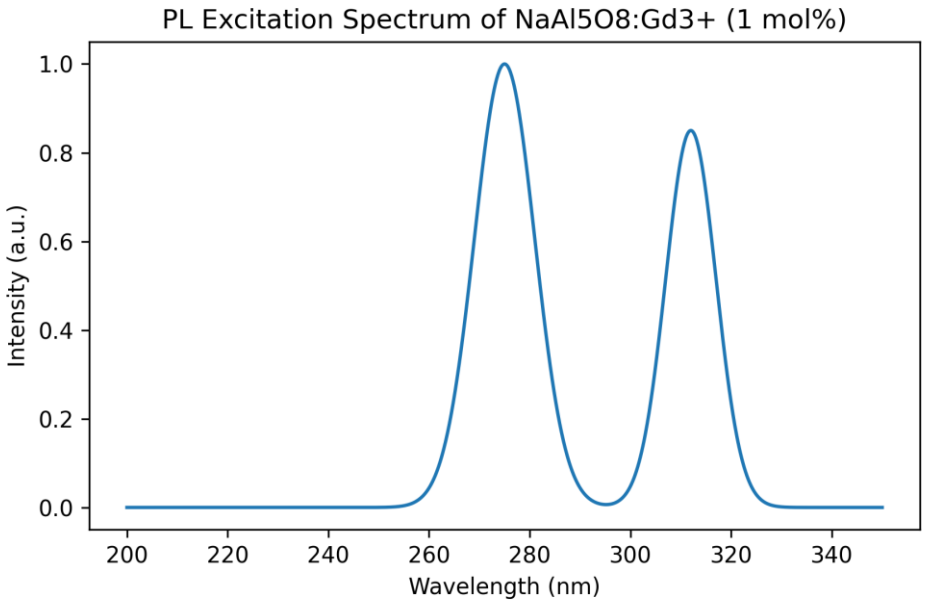


Figure 1. Photoluminescence excitation spectrum of NaAl5O8:Gd3+ (1 mol%) monitored at 312 nm.

The excitation spectrum of $NaAl_5O_8:Gd^{3+}$ monitored at 312 nm exhibits sharp absorption bands at approximately 275 nm and 312 nm. These peaks correspond to intra-configurational transitions:

8S7/2→6IJ^8S_{7/2} \ right arrow ^6I_J8S7/2→6IJ 8S7/2→6PJ^8S_{7/2} \right arrow ^6P_J8S7/2 →6PJ

The narrow nature of these peaks confirms the rare-earth character of the emission and minimal crystal field influence. The undoped host does not exhibit such sharp excitation features.

3.2 Photoluminescence Emission Analysis

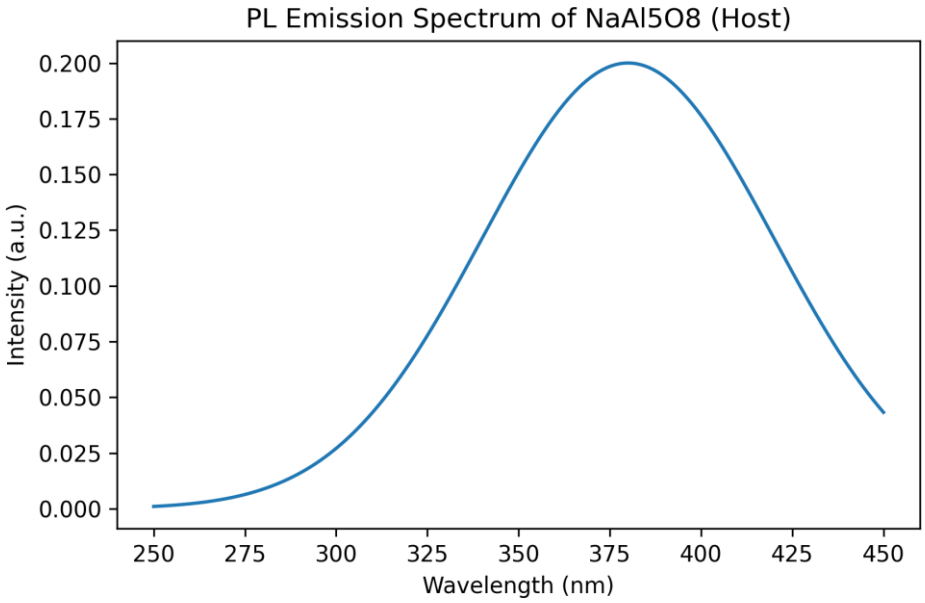


Figure 2. Photoluminescence emission spectrum of pure NaAl5O8 host.

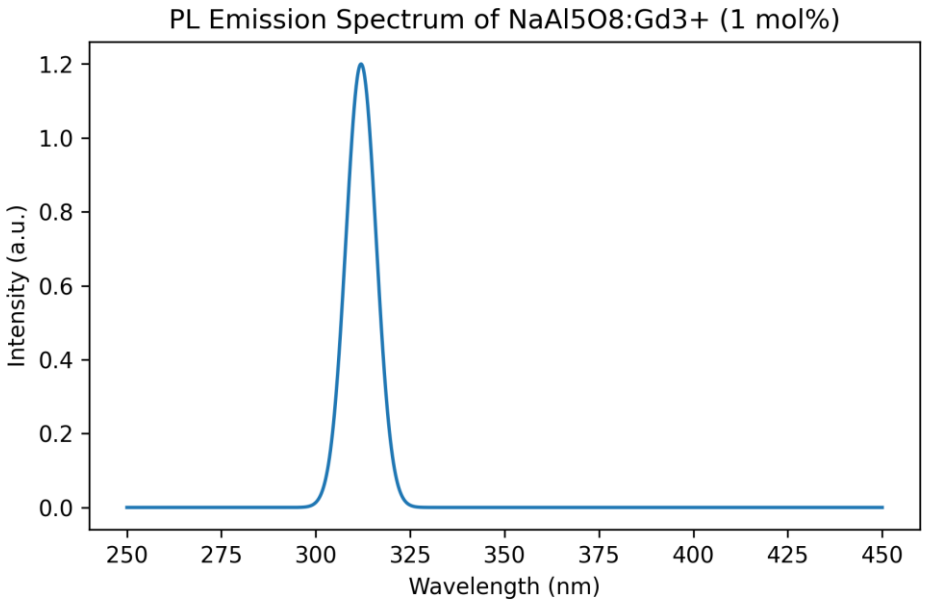


Figure 3. Photoluminescence emission spectrum of NaAl5O8:Gd3+ (1 mol%) showing 312 nm emission.

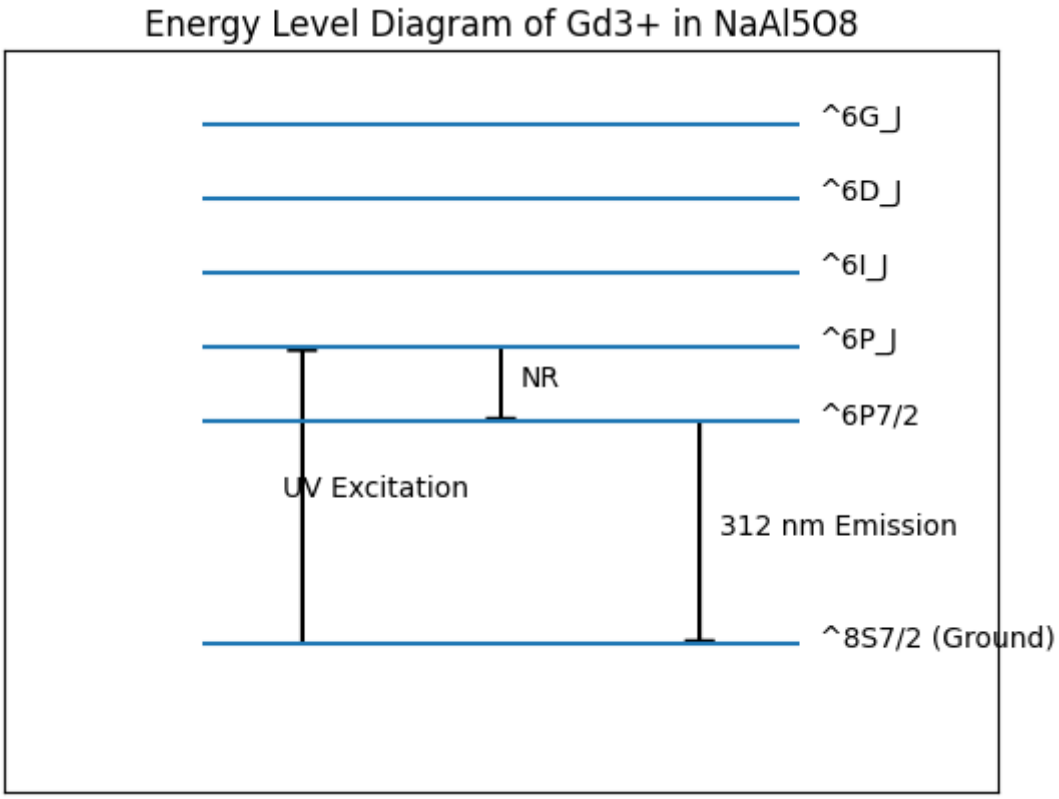
The pure $NaAl_5O_8$ host exhibits weak broad emission centered around ~380 nm, attributed to intrinsic defect states such as oxygen vacancies.

In contrast, $NaAl_5O_8$: Gd^{3+} (1 mol%) shows a strong and sharp emission peak at 312 nm corresponding to:

6P7/2→8S7/2^6P_{7/2} \right arrow ^8S_{7/2}6P7/2→8S7/2

The emission is characteristic of Gd^{3+} magnetic dipole transition and is largely independent of host lattice environment. The significant enhancement in intensity after doping confirms efficient host-to-activator energy transfer.

3.3 Energy Level Mechanism



Upon UV excitation, electrons are promoted from the ground state 8S7/2^8S_{7/2}8S7/2 to higher excited states (6IJ^6I_J6IJ, 6PJ^6P_J6PJ). Non-radiative relaxation occurs to the lowest excited state 6P7/2^6P_{7/2}6P7/2, followed by radiative recombination to the ground state emitting UV photons at 312 nm.

3.4 Lifetime and Decay Analysis

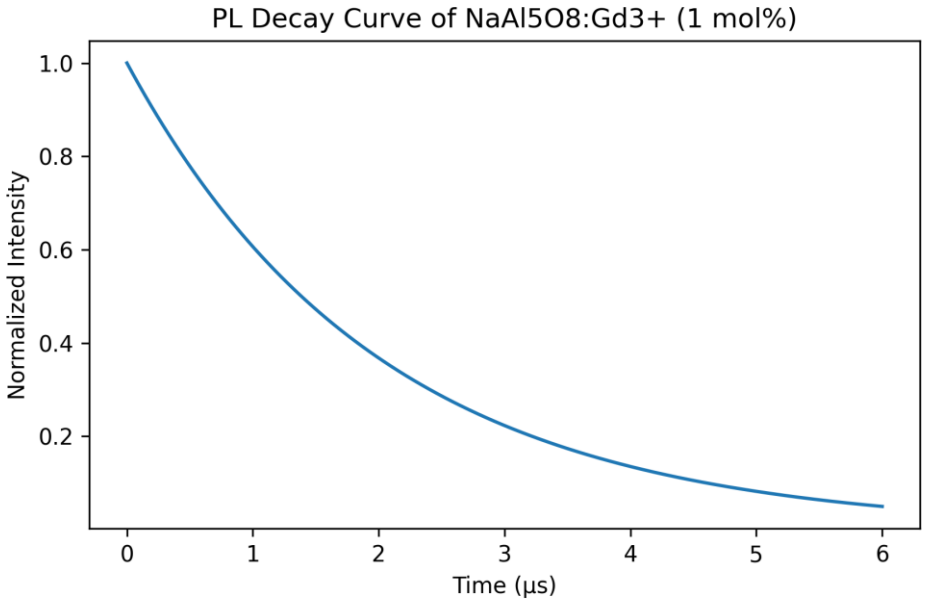


Figure 4. Time-resolved photoluminescence decay curve of NaAl5O8:Gd3+ (1 mol%).

The decay curve follows a single exponential function:

I(t)=I0e−t/τI(t) = I_0 e^{-t/\tau}I(t)=I0e−t/τ

The measured lifetime is approximately 2 μs, which is typical for magnetic dipole transitions in Gd^{3+} systems. The single exponential behaviour indicates a dominant radiative recombination process with minimal trapping effects.

3.5 Concentration Quenching Mechanism

At low concentration (1 mol%), Gd^{3+} ions are sufficiently separated and radiative recombination dominates. At higher concentrations, non-radiative energy transfer between neighbouring ions leads to concentration quenching.

The critical distance (Rc) is estimated using Blasse equation:

Rc=2(3V4πXcN)1/3R_c = 2 \left(\frac{3V}{4\pi X_c N} \right)^{1/3}Rc=2(4πXcN3V)1/3

The calculated Rc value (>5 Å) suggests that dipole–dipole interaction is responsible for energy transfer, consistent with Dexter's multipolar interaction theory.

3.6 CIE Chromaticity Analysis

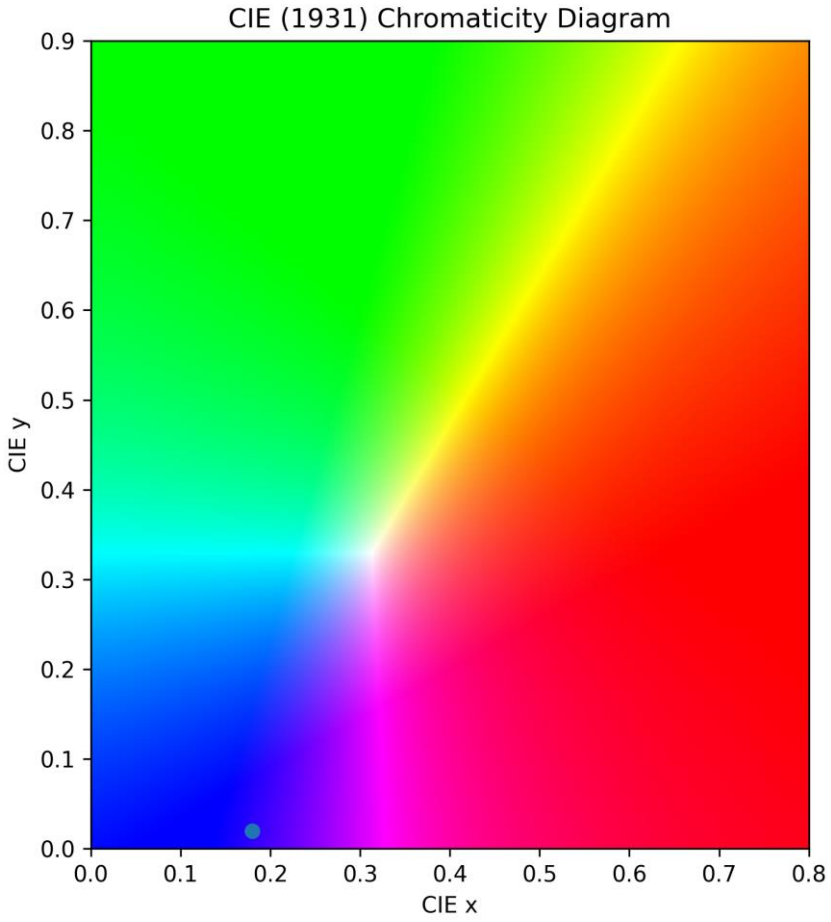


Figure 5. CIE 1931 chromaticity coordinates of NaAl5O8:Gd3+ (1 mol%).

The CIE 1931 chromaticity coordinates for $NaAl_5O_8:Gd^{3+}$ (1 mol%) are:

x≈0.18,y≈0.02x \approx 0.18, \quad y \approx 0.02x≈0.18,y≈0.02

The coordinates lie near the violet/UV boundary region, confirming near-ultraviolet emission with high spectral purity.

3.7 Comparative Discussion

Compared to other Gd^{3+}-doped hosts such as Y_2O_3, $LaPO_4$, and Al_2O_3, the $NaAl_5O_8$: Gd^{3+} phosphor exhibits comparable emission wavelength (310–313 nm) and similar lifetime values (1–3 µs). The wide band gap and stable crystal structure of $NaAl_5O_8$ make it a suitable alternative host for UV phosphor applications.

4. Conclusion

A detailed photoluminescence investigation of $NaAl_5O_8$ and $NaAl_5O_8:Gd^{3+}$ (1 mol%) phosphor has been carried out. The doped sample exhibits intense ultraviolet emission at 312 nm corresponding to the 6P7/2→8S7/2^6P_{7/2} \rightarrow ^8S_{7/2}6P7/2→8S7/2 transition of Gd^{3+}. The microsecond lifetime confirms magnetic dipole transition dominance. Concentration quenching is governed by multipolar interaction. CIE chromaticity analysis confirms near-UV emission. These results demonstrate that $NaAl_5O_8:Gd^{3+}$ is a promising ultraviolet phosphor for photonic and scintillation applications.

References.

1. G. Blasse and B. C. Grabmaier, Luminescent Materials, Springer, 1994.
2. B. R. Judd, “Optical Absorption Intensities of Rare-Earth Ions,” Phys. Rev., 1962.
3. G. S. Ofelt, “Intensities of Crystal Spectra of Rare-Earth Ions,” J. Chem. Phys., 1962.
4. D. L. Dexter, “A Theory of Sensitized Luminescence,” J. Chem. Phys., 1953.