

# Microwave-Assisted Synthesis of $\text{Li}_3\text{Ba}_2\text{Gd}_3(\text{MoO}_4)_8$ Phosphors Doped with $\text{Pr}^{3+}$ and $\text{Sm}^{3+}$ for High-Performance Red Emission in LED Applications

Shashi Pandey<sup>1,\*</sup>, Aparna Nadgowda<sup>2</sup>, Chitra Khade<sup>3</sup>, Purushottam Naktode<sup>4</sup>

## Abstract

*In this study, we report the successful synthesis of  $\text{Li}_3\text{Ba}_2\text{Gd}_3(\text{MoO}_4)_8$  ( $\text{RE}^{3+} = \text{Pr}^{3+}, \text{Sm}^{3+}$ ) phosphors using a novel, microwave-assisted solid-state reaction method at ambient temperature. The synthesis involved the use of analytical grade reagents including Lithium Nitrate ( $\text{LiNO}_3$ ), Barium Nitrate, Gadolinium Nitrate ( $\text{Gd}(\text{NO}_3)_3 \cdot 6\text{H}_2\text{O}$ ), Ammonium Molybdate ( $(\text{NH}_4)_6\text{Mo}_7\text{O}_{24} \cdot 24\text{H}_2\text{O}$ ), and high-purity oxides of Praseodymium ( $\text{Pr}_2\text{O}_3$ ) and Samarium ( $\text{Sm}_2\text{O}_3$ ). The reagents were mixed in stoichiometric ratios, ground thoroughly in a pestle and mortar, and then subjected to microwave irradiation for 10 minutes. The resultant powders were washed, dried, and ground again for further analysis. Under blue light excitation at 450 nm, the  $\text{Li}_3\text{Ba}_2\text{Gd}_3(\text{MoO}_4)_8:0.07\text{Pr}^{3+}$  phosphor exhibits a prominent red emission peak at 645 nm. The maximum optical intensity was obtained for 7 mol% doping concentration of both  $\text{Pr}^{3+}$  and  $\text{Sm}^{3+}$  ions.  $\text{Pr}^{3+}$  ions, characterized by their  $4f^2$  electronic configuration, display a broad spectrum of emissions across different wavelengths: red emission from the  $^1\text{D}_2$  level, green from the  $^3\text{P}_0$  level, blue from the  $^1\text{S}_0$  level, and ultraviolet from the  $4f$  to  $5d$  state transition. These multiple emission peaks indicate the versatility of  $\text{Pr}^{3+}$  ions in generating various colors under different excitation conditions. Similarly, when excited with near-UV light at 404 nm, the  $\text{Li}_3\text{Ba}_2\text{Gd}_3(\text{MoO}_4)_8:0.07\text{Sm}^{3+}$  phosphor demonstrates intense red emission lines at 605 nm. The optimal  $\text{Sm}^{3+}$  doping concentration was also determined to be 7 mol%.  $\text{Sm}^{3+}$  ions, with their  $4f^5$  electronic configuration, exhibit intense orange-red fluorescence within the visible spectrum. This strong red emission is attributed to transitions from the  $^4\text{G}_{5/2}$  excited state to various lower-lying states such as  $^6\text{H}_{5/2}$ ,  $^6\text{H}_{7/2}$ , and  $^6\text{H}_{9/2}$ , resulting in the observed sharp emission peaks. Remarkably, the red emission intensities of these phosphors are comparable to that of the conventional  $\text{Y}_2\text{O}_3\text{S}^{3+}$  red phosphor, which is widely used in commercial applications. This comparison underscores the efficiency and potential of  $\text{Li}_3\text{Ba}_2\text{Gd}_3(\text{MoO}_4)_8:0.07\text{Pr}^{3+}$  and  $\text{Li}_3\text{Ba}_2\text{Gd}_3(\text{MoO}_4)_8:0.07\text{Sm}^{3+}$  phosphors as high-performance red-emitting materials. These findings highlight the potential of  $\text{Li}_3\text{Ba}_2\text{Gd}_3(\text{MoO}_4)_8:0.07\text{Pr}^{3+}$  and  $\text{Li}_3\text{Ba}_2\text{Gd}_3(\text{MoO}_4)_8:0.07\text{Sm}^{3+}$  phosphors for integration into near-UV and blue light GaN-based white LEDs. Their superior performance, stability, and compatibility with existing LED technology suggest that these phosphors could serve as promising candidates for next-generation solid-state lighting applications. The successful synthesis and characterization of these phosphors pave the way for further exploration and optimization of rare-earth-doped phosphors in advanced lighting technologies, potentially leading to more efficient and versatile lighting solutions.*

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could serve as promising candidates for next-generation solid-state lighting applications. The successful synthesis and characterization of these phosphors pave the way for further exploration and optimization of rare-earth-doped phosphors in advanced lighting technologies, potentially leading to more efficient and versatile lighting solutions.

**Keywords:** Luminescent, material, Red, Phosphors, SSM.

## INTRODUCTION

Rare earth elements have received a tremendous amount of study in recent years, because of its use as different magnets, luminous phosphors, catalysts

and other light devices. Phosphors, luminous materials that emit light, have been the focus of current research. These rare earth elements have played very important role in different electronic devices such as White light emitting diodes (w-LEDs), the screen of TVs and computers, radiation imaging sensors, biological imaging, and lasers in some instruments or machines used in medical field [1–3]. As compared to traditional incandescent and fluorescent light sources, the W-LEDs have several advantages including long lifetime, increased luminous efficiency, dependability and energy efficiency, have gotten a lot of attention recently. Because of this, current research focuses on the spectroscopic features of basic materials having rare earth elements for usage in white LEDs [4–6]. Fluorescent lamps and other phosphor-related goods rely heavily on these raw ingredients, making them major consumers in the lighting sector. Manufacturing these lamps with the phosphor coating is now a relatively straightforward operation, which is ideal for the business. To evaluate the luminescence efficiency of rare-earth-doped inorganic materials, several key processes are typically employed for primary excitation energy generation. Initially, the host lattice absorbs the excitation energy, which is subsequently transferred to the activator. The energy then moves from the activator to its neighbouring ions, culminating in the activator emitting the energy optically [7].

Because of its typical energy level pattern, the  $\text{Pr}^{3+}$  ion whose configuration is  $[\text{Xe}] 4f^2$  acts as unique activators [8]. The  $\text{Pr}^{3+}$  ion may radiate light in the range from the light of visible wavelength to infrared light wavelength spectrum by transitioning between different energy levels [9]. So, several host materials were used to create a variety of phosphors doped with  $\text{Pr}^{3+}$ , like Gadolinium Oxysulfide doped with Praseodymium, Calcium Titanate doped with Praseodymium, Barium Molybdate doped with Praseodymium, Lanthanum Magnesium Aluminate doped with Praseodymium [10–13]. If a host material can be doped solely with  $\text{Pr}^{3+}$  ions to emit both green and red light simultaneously, pure white light can be achieved by exciting it with a blue light chip. This capability is crucial for its application in white LEDs (w-LEDs) [14].

Here we are presenting a preliminary report on the formation  $\text{Pr}^{3+}$  doped  $\text{Li}_3\text{Ba}_2\text{Gd}_3(\text{MoO}_4)_8$  and  $\text{Pr}^{3+}$  doped  $\text{Li}_3\text{Ba}_2\text{Gd}_3(\text{MoO}_4)_8$  using microwave metathesis approach. Metathesis reactions taking place in solid state are very uncommon. This microwave assisted synthesis process is highly exothermic, extremely rapid, self energetic reactions that produces crystalline product in very short span of time with different microstructures and easy removal of the by-product using water.

## LUMINESCENCE PROPERTIES OF NOVEL $\text{Li}_3\text{Ba}_2\text{Gd}_3(\text{MoO}_4)_8\cdot\text{RE}^{3+}$ ( $\text{RE}^{3+} = \text{Pr}^{3+}, \text{Sm}^{3+}$ ) RED PHOSPHORS

### Experimental Process

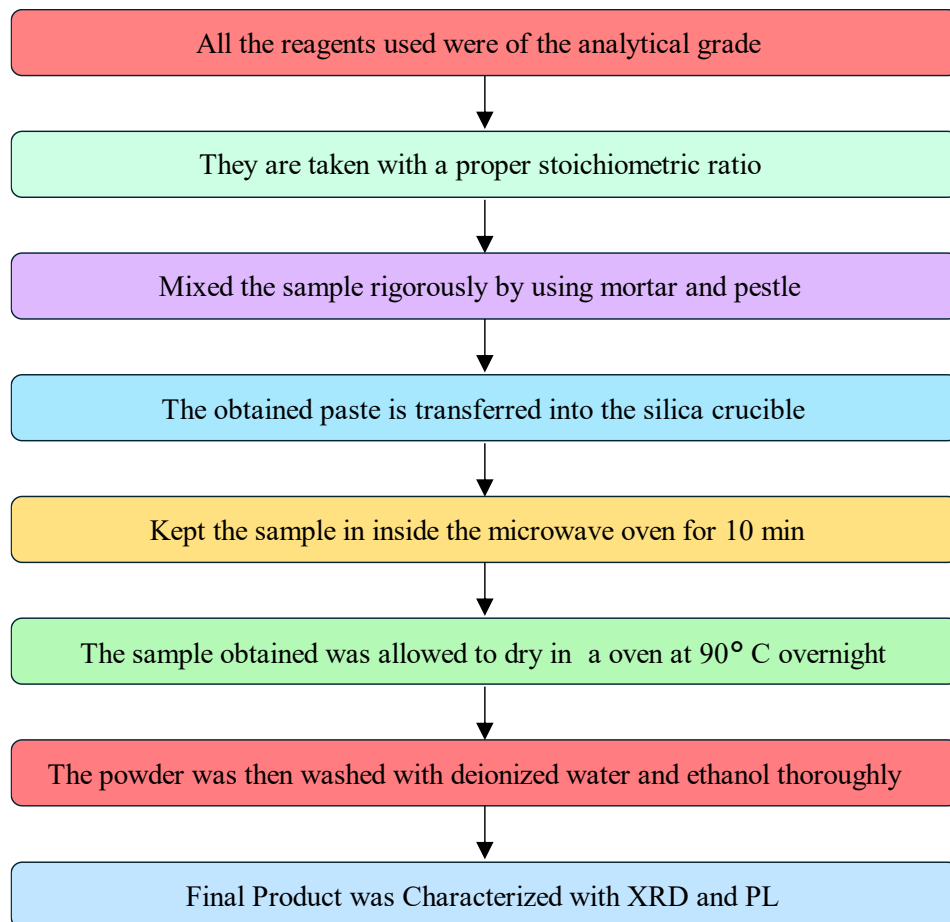
$\text{Li}_3\text{Ba}_2\text{Gd}_3(\text{MoO}_4)_8$  samples were prepared using the microwave assisted solid state procedure that is indicated in Figure 1, with high-purity Samarium Oxide ( $\text{Sm}_2\text{O}_3$ ) and Praseodymium Oxide as the dopants. All reagents used for the synthesis were of analytical grade (Figure 1)

### Structural Analysis

#### Excitation Spectrum

- Monitoring Wavelength: The excitation spectrum is obtained while monitoring the emission at 645 nm.
- Prominent Broad Band:
  - Range: 250-350 nm
  - Maximum Intensity: 293 nm
  - Cause: Charge transfer transition
- Fine and Closed Absorption Lines:
  - Range: 445-510 nm
  - Cause: 4f-4f orbit transitions by  $\text{Pr}^{3+}$  ions
- Prominent Peaks in Excitation Bands:
  - 452 nm: Transition from  $^3\text{H}_4$  to  $^3\text{P}_2$

- 474 nm: Transition from  $^3H_4$  to  $^3P_1 + ^1I_6$
- 487 nm: Transition from  $^3H_4$  to  $^3P_0$
- Maximum Excitation Wavelength: 452 nm



**Figure 1.** Experimental process for synthesis of  $Li_3Ba_2Gd_3(MoO_4)_8:x Pr^{3+}$  and  $Li_3Ba_2Gd_3(MoO_4)_8:x Sm^{3+}$ .

### Emission Spectrum

The emission spectra would typically show the characteristic peaks of  $Pr^{3+}$  ions when excited at their corresponding excitation wavelengths. For this compound, the emission spectrum observed at 645 nm would typically be associated with the  $^3P_0 \rightarrow ^3H_6$  transition of  $Pr^{3+}$  ions.

### Analysis for Different x Values (0.01, 0.03, 0.05, 0.07, 0.09 mol)

The concentration of  $Pr^{3+}$  ions (denoted by x) might influence the intensity and sharpness of the peaks in the excitation and emission spectra. With increasing x, we can observe variations in the spectral intensity due to concentration quenching effects or enhanced luminescence due to better energy transfer mechanisms.

- *Excitation Spectrum:* Shows prominent broad bands and fine absorption lines due to charge transfer and 4f-4f transitions.
- *Prominent Peaks:* Observed at 452 nm, 474 nm, and 487 nm due to specific f-f transitions of  $Pr^{3+}$  ions.
- *Emission Spectrum:* Monitored at 645 nm, associated with the  $^3P_0 \rightarrow ^3H_6$  transition of  $Pr^{3+}$  ions.
- *Concentration Variations (x):* Affect spectral intensity and peak sharpness.

Emission and Excitation Spectra Analysis of  $Li_3Ba_2Gd_3(MoO_4)_8:n, Pr^{3+}$  and  $Li_3Ba_2Gd_3(MoO_4)_8 Sm^{3+}$

**Emission Spectrum**

- **Excitation Wavelength:** 452 nm
- **Main Emission Peaks:**
  - **594 nm:**  $^3\text{P}_0 \rightarrow ^3\text{H}_5$
  - **618 nm:**  $^3\text{P}_0 \rightarrow ^3\text{H}_6$
  - **645 nm:**  $^3\text{P}_0 \rightarrow ^3\text{F}_2$  (Prominent peak indicating red emission)
  - **680 nm:**  $^3\text{P}_0 \rightarrow ^3\text{F}_3$
- **Observation:**
  - The emission spectrum displays typical transitions characteristic of  $\text{Pr}^{3+}$  ions.

**Effect of Dopant Concentration (x)**

- **Relative Emission Intensity:**
  - Increases with increasing  $\text{Pr}^{3+}$  concentration.
  - Maximum intensity observed at  $x = 0.07$  mol.
  - Beyond  $x = 0.07$  mol, a decrease in emission intensity due to concentration quenching is observed.
- $\text{Li}_3\text{Ba}_2\text{Gd}_3(\text{MoO}_4)_8$
- $\text{Sm}^{3+}$  Phosphors

**Excitation Spectrum**

- **Monitoring Wavelength:** 605 nm
- **Prominent Broad Band:**
  - **Range:** 220-335 nm
  - **Cause:** Charge transfer transition in the host materials.
- **Fine Peaks:**
  - **Range:** 330-500 nm

**Emission Spectrum**

- **Excitation Wavelength:** 404 nm
- **Main Emission Peaks:**
  - **570 nm:**  $^4\text{G}_{5/2} \rightarrow ^6\text{H}_{5/2}$
  - **605 nm:**  $^4\text{G}_{5/2} \rightarrow ^6\text{H}_{7/2}$  (Maximum emission intensity indicating red emission)
  - **649 nm:**  $^4\text{G}_{5/2} \rightarrow ^6\text{H}_{9/2}$
- **Observation:**
  - The emission spectrum shows sharp and prominent fine lines due to 4f-4f transitions of  $\text{Sm}^{3+}$  ions.
  - The peak at 605 nm is the most intense, representing the red emission (Figure 2–5).

**Effect of Dopant Concentration (x)**

- **Relative Emission Intensity:**
  - Maximum emission intensity at 605 nm observed for  $x = 0.07$  mol.
  - The optimal concentration for prominent emission is 7 mol%.
- **$\text{Pr}^{3+}$  Doped Phosphors:**
  - **Excitation:** Maximum at 452 nm, with emission peaks at 594, 618, 645, and 680 nm.
  - **Optimal Concentration:** 0.07 mol (for maximum red emission intensity at 645 nm).
- **$\text{Sm}^{3+}$  Doped Phosphors:**
  - **Excitation:** Monitored at 605 nm, with broad bands from 220-335 nm and fine peaks from 330-500 nm.
  - **Emission:** Peaks at 570, 605, and 649 nm, with the maximum intensity at 605 nm.
  - **Optimal Concentration:** 0.07 mol (for maximum red emission intensity at 605 nm).

## ANALYSIS AND DISCUSSION

### Experimental Process

A series of phosphors  $\text{Li}_3\text{Ba}_2\text{Gd}_3(\text{MoO}_4)_8$

$\text{Pr}^{3+}$  ( $x = 0.01$  and  $0.09$  mol) and  $\text{Li}_3\text{Ba}_2\text{Gd}_3(\text{MoO}_4)_8$

$\text{Sm}^{3+}$  ( $x = 0.01$  and  $0.09$  mol) samples were synthesized using the microwave-assisted solid-state metathesis (SSM) process. The reagents used for the preparation were of analytical grade:

- **$\text{Li}_3\text{Ba}_2\text{Gd}_3(\text{MoO}_4)_8$**

**$\text{Pr}^{3+}$ :** Lithium Nitrate ( $\text{LiNO}_3$ ), Barium Nitrate, Gadolinium Nitrate ( $\text{Gd}(\text{NO}_3)_3 \cdot 6\text{H}_2\text{O}$ ), Ammonium Molybdate ( $(\text{NH}_4)_6\text{Mo}_7\text{O}_{24} \cdot 24\text{H}_2\text{O}$ ), and Praseodymium Oxide ( $\text{Pr}_2\text{O}_3$ ).

- **$\text{Li}_3\text{Ba}_2\text{Gd}_3(\text{MoO}_4)_8$**

**$\text{Sm}^{3+}$ :** Lithium Nitrate ( $\text{LiNO}_3$ ), Barium Nitrate, Gadolinium Nitrate ( $\text{Gd}(\text{NO}_3)_3 \cdot 6\text{H}_2\text{O}$ ), Ammonium Molybdate ( $(\text{NH}_4)_6\text{Mo}_7\text{O}_{24} \cdot 24\text{H}_2\text{O}$ ), and Samarium Oxide ( $\text{Sm}_2\text{O}_3$ ).

The preparation process involved:

1. Mixing the reagents in a stoichiometric ratio using a pestle and mortar.
2. Transferring the paste to a silica crucible and placing it in a microwave oven for 10 minutes.
3. Washing the resulting powder with deionized water and ethanol, followed by drying at  $90^\circ\text{C}$  for 24 hours.
4. Grinding the dried sample in an agate mortar for further investigation.

### Structural Analysis

Figure 6 shows the XRD patterns of the samples, indicating a crystalline single-phase formation with a monoclinic structure ( $\text{C2/c}$  space group). The crystal structure includes:

- Tetrahedral coordination of molybdenum ions.
- Barium ions positioned at the 2-fold axis, coordinated by 10 oxygen ions.
- Lithium ions with asymmetrical octahedral coordination or 8-fold coordinated sites with  $\text{Ba}^{2+}$  and  $\text{Gd}^{3+}$ .
- **$\text{Li}_3\text{Ba}_2\text{Gd}_3(\text{MoO}_4)_8$**

**$\text{Pr}^{3+}$  ( $x = 0.01$  and  $0.09$  mol):**  $\sim 86$  nm

- **$\text{Li}_3\text{Ba}_2\text{Gd}_3(\text{MoO}_4)_8$**

**$\text{Sm}^{3+}$  ( $x = 0.01$  and  $0.09$  mol):**  $\sim 64$  nm

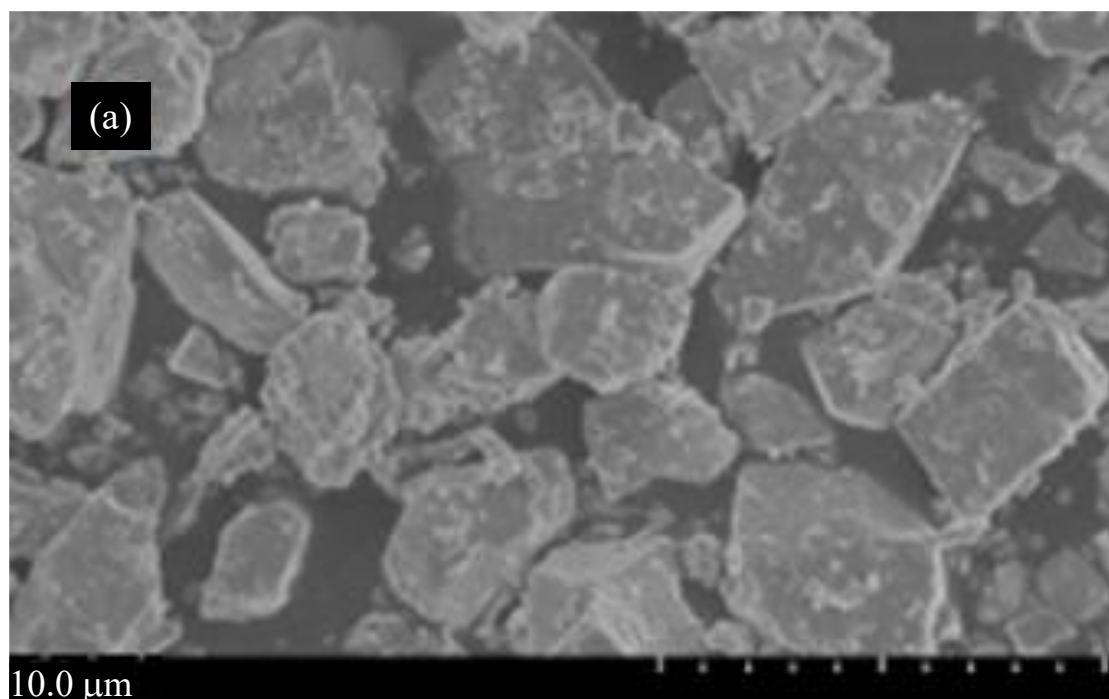
### Morphological Analysis

SEM images (Figure 7) reveal:

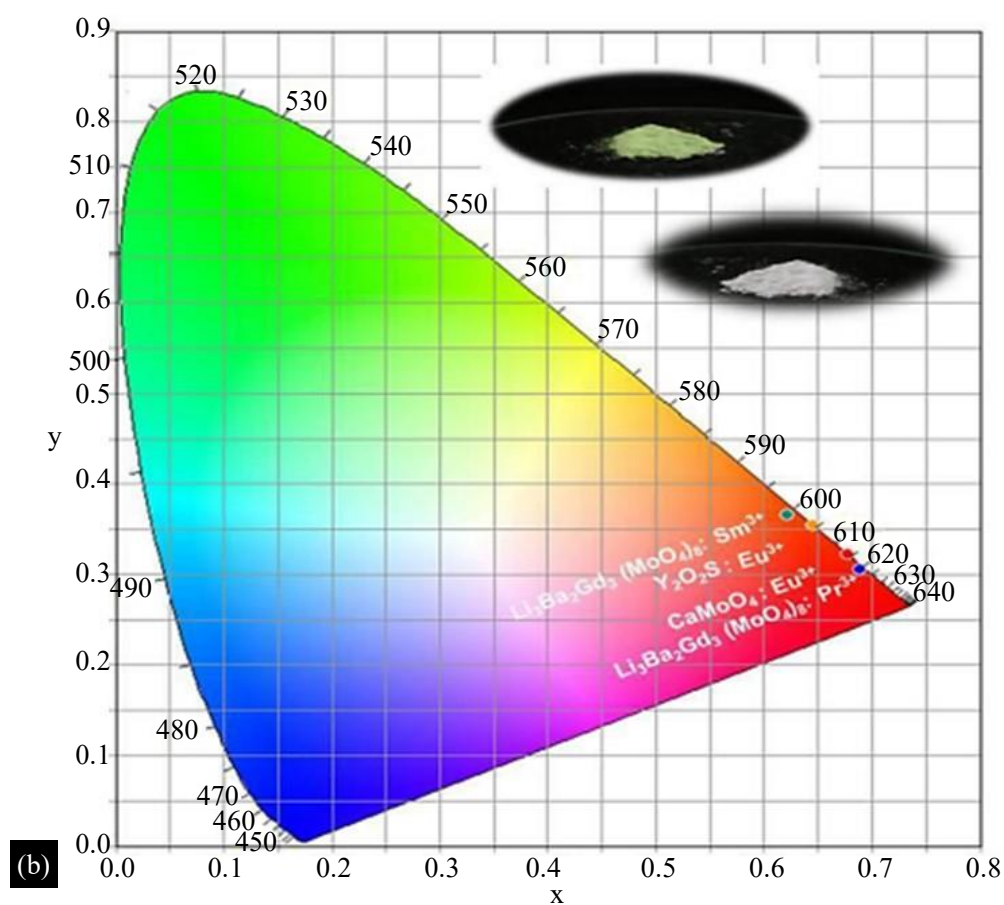
- Large agglomerated particles ( $3\text{--}5\ \mu\text{m}$ ) with irregular shapes surrounded by smaller particles ( $\sim 500$  nm).
- High Li content promoting significant particle growth at lower sintering temperatures.
- $\text{Pr}^{3+}$  concentration changes having minimal effect on morphology.

### Photoluminescence Properties

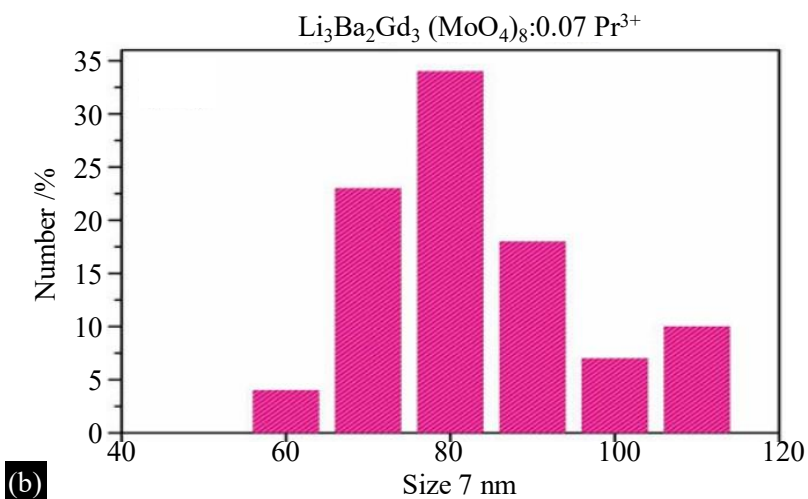
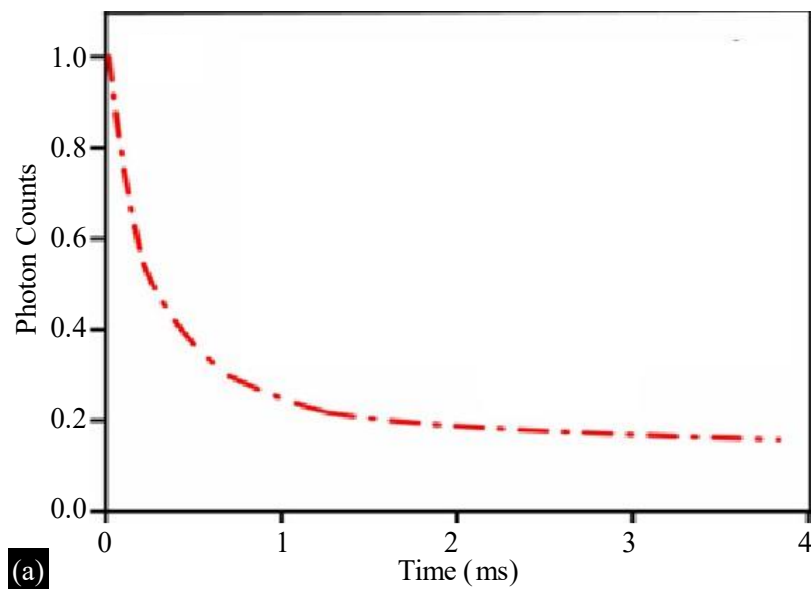
Figure 8 and 9 display the excitation and emission spectra of  $\text{Li}_3\text{Ba}_2\text{Gd}_3(\text{MoO}_4)_8$



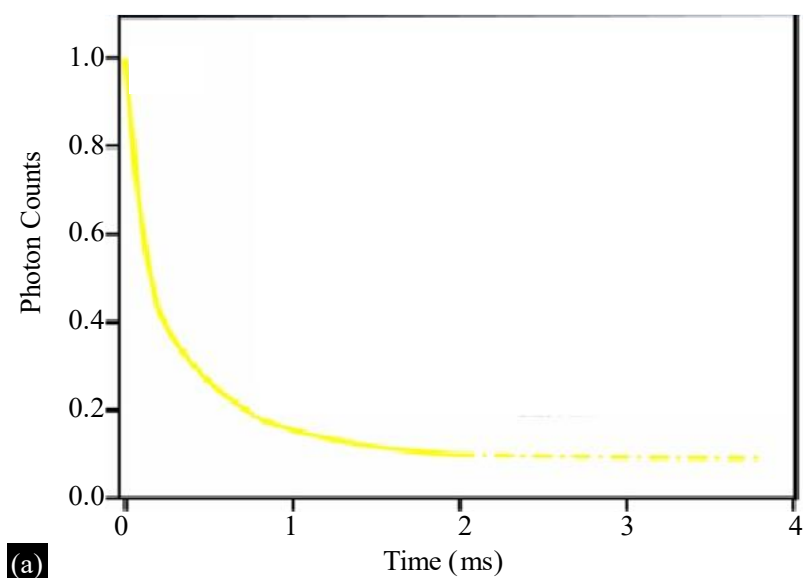
**Figure 2.** (a) SEM micrograph of  $\text{Li}_3\text{Ba}_2\text{Gd}_3(\text{MoO}_4)_8$ : $x\text{Sm}^{3+}$  ( $x = 0.09$  mol).

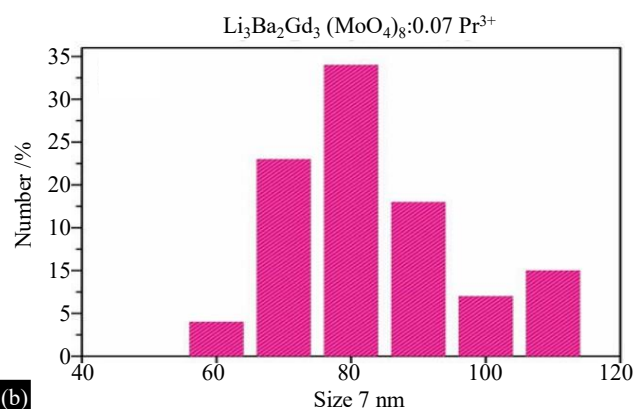


**Figure 2.** (b) CIE chromaticity diagram for  $\text{Pr}^{3+}$  doped  $\text{Li}_3\text{Ba}_2\text{Gd}_3(\text{MoO}_4)_8$ ,  $\text{Sm}^{3+}$  doped  $\text{Li}_3\text{Ba}_2\text{Gd}_3(\text{MoO}_4)_8$ ,  $\text{Eu}^{3+}$  doped  $\text{CaMoO}_4$ , and  $\text{Y}_2\text{O}_2\text{S}^{3+}$  phosphors.



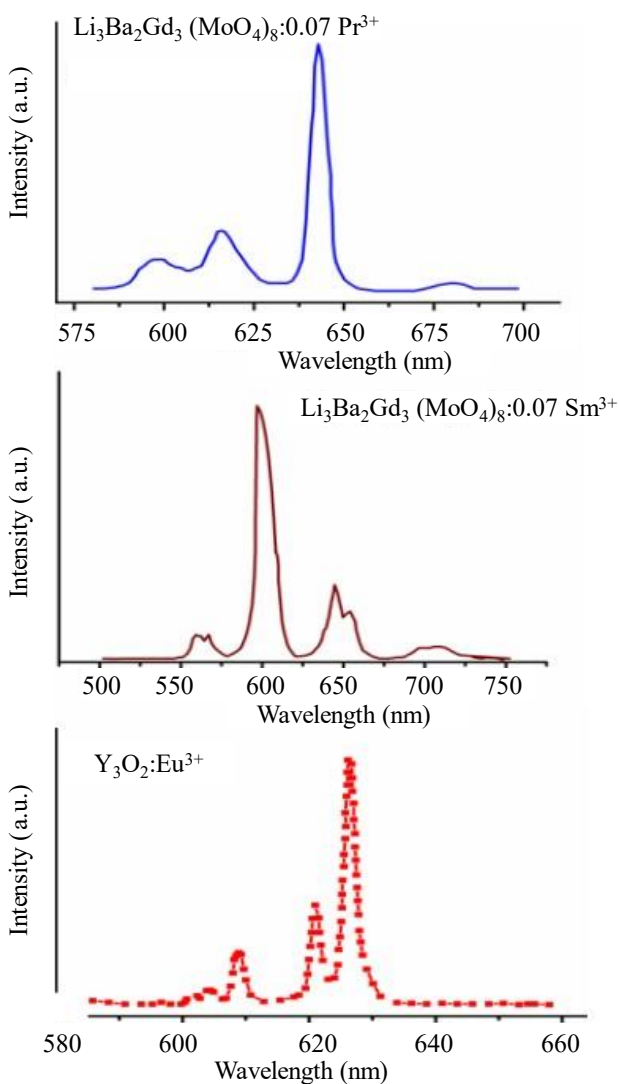
**Figure 3.** (a) Luminescent decay curve at 645 nm for  $\text{Pr}^{3+}$  ions in  $\text{Li}_3\text{Ba}_2\text{Gd}_3(\text{MoO}_4)_8:0.07 \text{Pr}^{3+}$  phosphor. (b) Particle size distribution of  $\text{Li}_3\text{Ba}_2\text{Gd}_3(\text{MoO}_4)_8:0.07 \text{Pr}^{3+}$  phosphor.



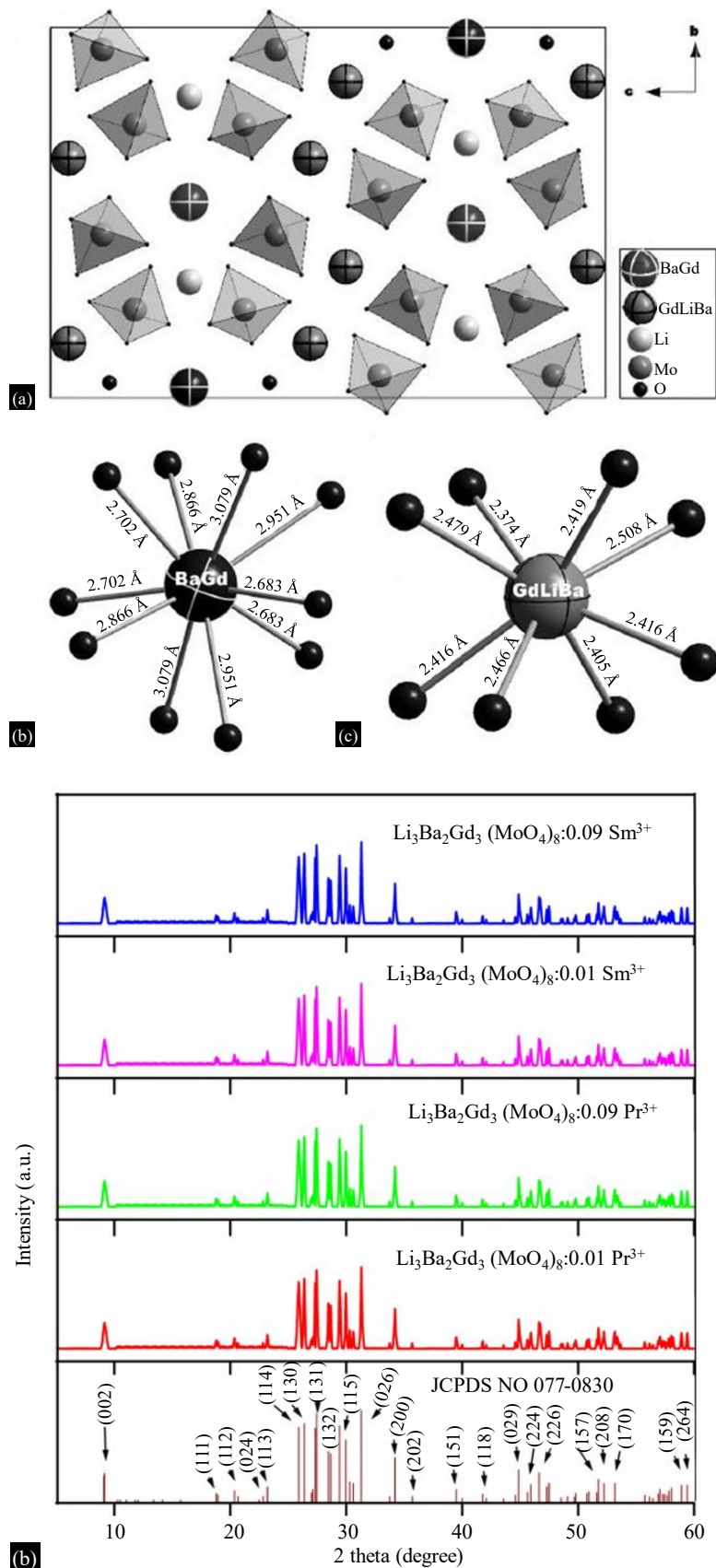


(b)

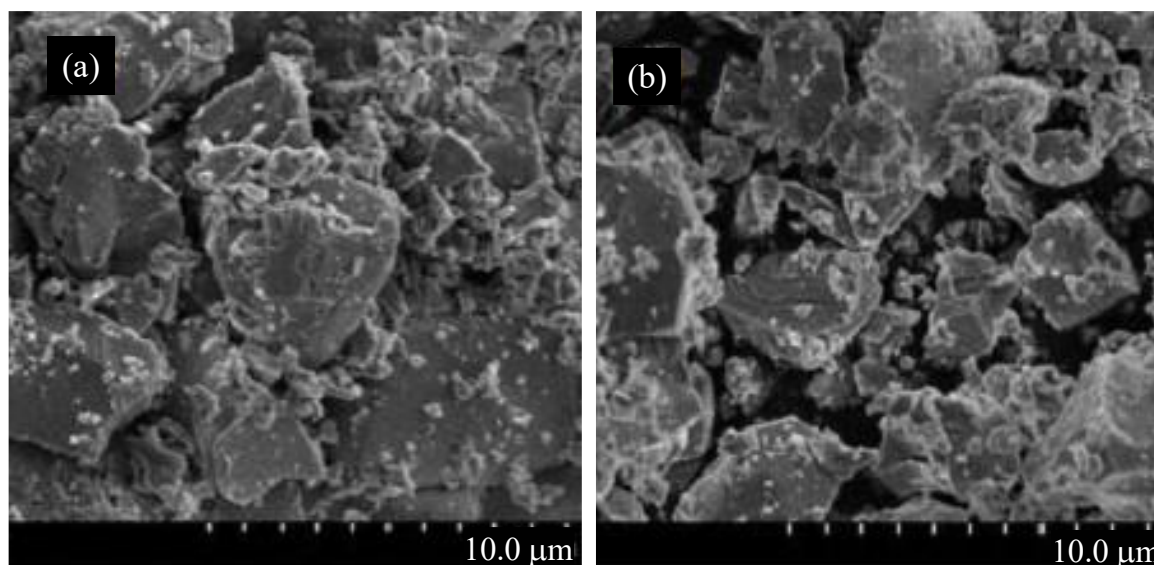
**Figure 4.** Presents two key analyses for the  $\text{Li}_3\text{Ba}_2\text{Gd}_3(\text{MoO}_4)_8:0.07\text{Sm}^{3+}$  phosphor. Panel (a) shows the room temperature luminescent decay curve at 605 nm for  $\text{Sm}^{3+}$  ions. This decay curve was fitted using a single-exponential function to determine the lifetime of the  $\text{Sm}^{3+}$  ions, which was found to be 0.310 ms. Panel (b) depicts the particle size distribution for the  $\text{Li}_3\text{Ba}_2\text{Gd}_3(\text{MoO}_4)_8:0.07\text{Sm}^{3+}$  phosphor, indicating an average particle size of approximately 60 nm.



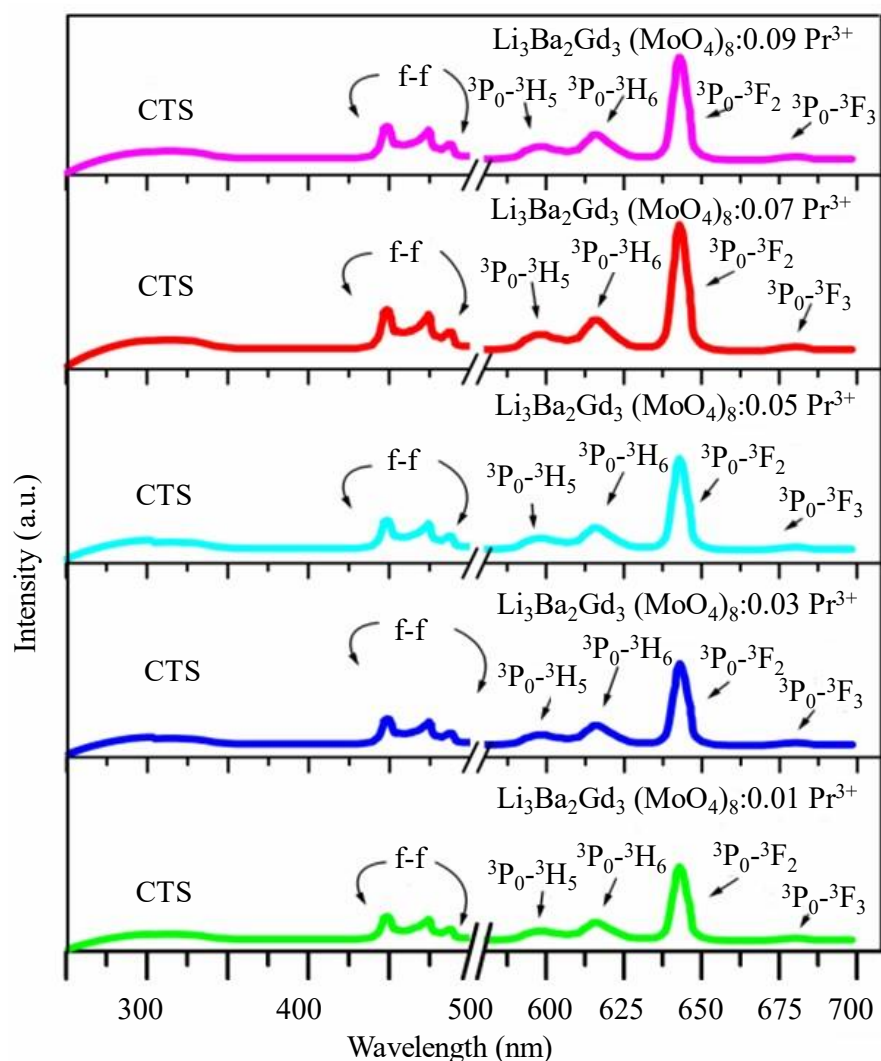
**Figure 5.** Comparison of emission spectra of  $\text{Li}_3\text{Ba}_2\text{Gd}_3(\text{MoO}_4)_8:0.07\text{Pr}^{3+}$ ,  $\text{Li}_3\text{Ba}_2\text{Gd}_3(\text{MoO}_4)_8:0.07\text{Sm}^{3+}$ , and  $\text{Y}_2\text{O}_3:\text{Eu}^{3+}$  phosphors.



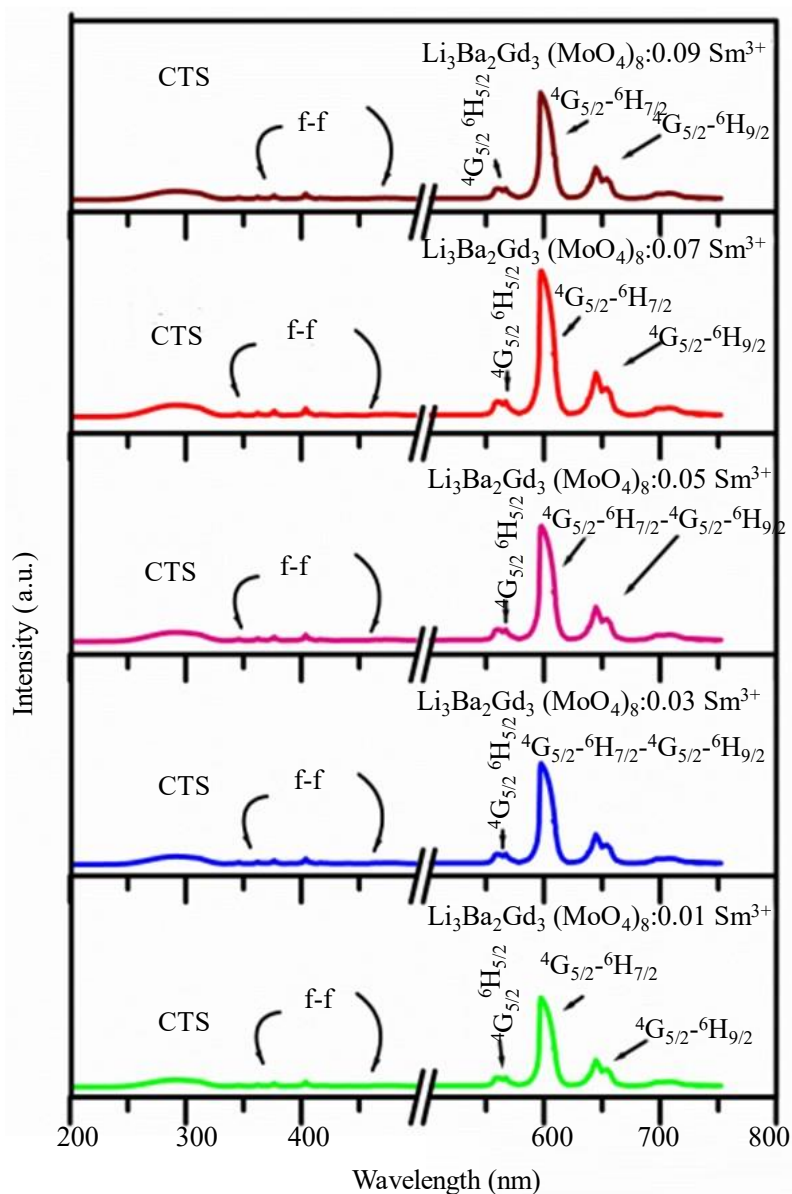
**Figure 6.** (a) Unit cell along the  $a$ -axis of  $\text{Li}_3\text{Ba}_2\text{Gd}_3(\text{MoO}_4)_8$ , (b) Ba, Gd site (c) Gd,Li,Ba site and (d) XRD patterns of  $\text{Li}_3\text{Ba}_2\text{Gd}_3(\text{MoO}_4)_8:x \text{ Pr}^{3+}$  and  $\text{Li}_3\text{Ba}_2\text{Gd}_3(\text{MoO}_4)_8:x \text{ Sm}^{3+}$ .



**Figure 7.** SEM pictures of (a)  $\text{Li}_3\text{Ba}_2\text{Gd}_3(\text{MoO}_4)_8$  and (b)  $\text{Li}_3\text{Ba}_2\text{Gd}_3(\text{MoO}_4)_8:0.09\text{Pr}^{3+}$  under magnification of 5.0k.



**Figure 8.** The PLE spectra and PL spectra of  $\text{Li}_3\text{Ba}_2\text{Gd}_3(\text{MoO}_4)_8:x\text{Pr}^{3+}$ .



**Figure 9.** The PL Excitation observed.

$\text{Pr}^{3+}$  and  $\text{Li}_3\text{Ba}_2\text{Gd}_3(\text{MoO}_4)_8$

- $\text{Sm}^{3+}$  phosphors, respectively.
- $\text{Li}_3\text{Ba}_2\text{Gd}_3(\text{MoO}_4)_8$
- $\text{Pr}^{3+}$  Phosphors
- **Excitation Spectrum:**
  - Monitoring wavelength: 645 nm
  - Broad band: 250-350 nm (Max intensity at 293 nm, charge transfer transition)
  - Fine lines: 445-510 nm (4f-4f transitions)
  - Prominent peaks: 452 nm ( $^3\text{H}_4 \rightarrow ^3\text{P}_2$ ), 474 nm ( $^3\text{H}_4 \rightarrow ^3\text{P}_1 + ^1\text{I}_6$ ), 487 nm ( $^3\text{H}_4 \rightarrow ^3\text{P}_0$ )
- **Emission Spectrum:**
  - Main peaks: 594 nm ( $^3\text{P}_0 \rightarrow ^3\text{H}_5$ ), 618 nm ( $^3\text{P}_0 \rightarrow ^3\text{H}_6$ ), 645 nm ( $^3\text{P}_0 \rightarrow ^3\text{F}_2$ , prominent red emission), 680 nm ( $^3\text{P}_0 \rightarrow ^3\text{F}_3$ )
  - Relative emission intensity increases up to  $x = 0.07$  mol, then decreases due to concentration quenching.
- $\text{Li}_3\text{Ba}_2\text{Gd}_3(\text{MoO}_4)_8$ :  $\text{Sm}^{3+}$  Phosphors

- **Excitation Spectrum:**
  - Monitoring wavelength: 605 nm
  - Broad band: 220-335 nm (charge transfer transition)
  - Fine peaks: 330-500 nm (intra-4f transitions)
- **Emission Spectrum:**
  - Main peaks: 570 nm ( $^4\text{G}_{5/2} \rightarrow ^6\text{H}_{5/2}$ ), 605 nm ( $^4\text{G}_{5/2} \rightarrow ^6\text{H}_{7/2}$ , prominent red emission), 649 nm ( $^4\text{G}_{5/2} \rightarrow ^6\text{H}_{9/2}$ )
  - Relative emission intensity increases up to  $x = 0.07$  mol, with the optimal concentration for prominent emission at 7 mol%.
- **$\text{Pr}^{3+}$  Doped Phosphors:**
  - Maximum excitation at 452 nm, with prominent emission peaks at 594, 618, 645, and 680 nm.
  - Optimal concentration: 0.07 mol (for maximum red emission intensity at 645 nm).
- **$\text{Sm}^{3+}$  Doped Phosphors:**
  - Excitation monitored at 605 nm, with broad bands from 220-335 nm and fine peaks from 330-500 nm.
  - Emission peaks at 570, 605, and 649 nm, with maximum intensity at 605 nm.
  - Optimal concentration: 0.07 mol (for maximum red emission intensity at 605 nm).

This Tables 1–4 and analysis provide a comprehensive understanding of the luminescence properties of  $\text{Li}_3\text{Ba}_2\text{Gd}_3(\text{MoO}_4)_8$ :  $\text{Pr}^{3+}$  and  $\text{Li}_3\text{Ba}_2\text{Gd}_3(\text{MoO}_4)_8$ : $\text{Sm}^{3+}$  phosphors, highlighting their potential applications in white LEDs and display industries.

**Table 1.** Detailed Analysis of the Excitation and Emission Spectra

| Parameter                           | $\text{Li}_3\text{Ba}_2\text{Gd}_3(\text{MoO}_4)_8$<br>$\text{Pr}^{3+}$ Phosphors                                                                                                                              | $\text{Li}_3\text{Ba}_2\text{Gd}_3(\text{MoO}_4)_8$<br>$\text{Sm}^{3+}$ Phosphors                                                                                                  |
|-------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Excitation Wavelength               | 452 nm                                                                                                                                                                                                         | 404 nm                                                                                                                                                                             |
| Monitoring Wavelength               | 645 nm                                                                                                                                                                                                         | 605 nm                                                                                                                                                                             |
| Excitation Spectrum                 |                                                                                                                                                                                                                |                                                                                                                                                                                    |
| Prominent Broad Band                | 250-350 nm, Max Intensity: 293 nm (Charge transfer transition)                                                                                                                                                 | 220-335 nm (Charge transfer transition)                                                                                                                                            |
| Fine and Closed Absorption Lines    | 445-510 nm (4f-4f transitions of $\text{Pr}^{3+}$ ions)                                                                                                                                                        | 330-500 nm (Intra-4f transitions of $\text{Sm}^{3+}$ ions)                                                                                                                         |
| Prominent Peaks in Excitation Bands | 452 nm ( $^3\text{H}_4 \rightarrow ^3\text{P}_2$ ), 474 nm ( $^3\text{H}_4 \rightarrow ^3\text{P}_1 + ^1\text{I}_6$ ), 487 nm ( $^3\text{H}_4 \rightarrow ^3\text{P}_0$ )                                      | -                                                                                                                                                                                  |
| Emission Spectrum                   |                                                                                                                                                                                                                |                                                                                                                                                                                    |
| Emission Peaks                      | 594 nm ( $^3\text{P}_0 \rightarrow ^3\text{H}_5$ ), 618 nm ( $^3\text{P}_0 \rightarrow ^3\text{H}_6$ ), 645 nm ( $^3\text{P}_0 \rightarrow ^3\text{F}_2$ ), 680 nm ( $^3\text{P}_0 \rightarrow ^3\text{F}_3$ ) | 570 nm ( $^4\text{G}_{5/2} \rightarrow ^6\text{H}_{5/2}$ ), 605 nm ( $^4\text{G}_{5/2} \rightarrow ^6\text{H}_{7/2}$ ), 649 nm ( $^4\text{G}_{5/2} \rightarrow ^6\text{H}_{9/2}$ ) |
| Prominent Emission Peak             | 645 nm ( $^3\text{P}_0 \rightarrow ^3\text{F}_2$ , Red emission)                                                                                                                                               | 605 nm ( $^4\text{G}_{5/2} \rightarrow ^6\text{H}_{7/2}$ , Red emission)                                                                                                           |
| Effect of Dopant Concentration      |                                                                                                                                                                                                                |                                                                                                                                                                                    |
| Increase in Relative Emission       | Up to $x = 0.07$ mol                                                                                                                                                                                           | Up to $x = 0.07$ mol                                                                                                                                                               |
| Maximum Intensity                   | $x = 0.07$ mol                                                                                                                                                                                                 | $x = 0.07$ mol                                                                                                                                                                     |
| Concentration Quenching             | Decrease in emission intensity beyond $x = 0.07$ mol                                                                                                                                                           | -                                                                                                                                                                                  |
| Optimal Concentration for Emission  | $x = 0.07$ mol                                                                                                                                                                                                 | $x = 0.07$ mol                                                                                                                                                                     |

**Table 2.**  $\text{Pr}^{3+}$  and  $\text{Li}_3\text{Ba}_2\text{Gd}_3(\text{MoO}_4)_8$   $\text{Sm}^{3+}$  Phosphors.

| Parameter                          | $\text{Li}_3\text{Ba}_2\text{Gd}_3(\text{MoO}_4)_8$<br>$\text{Pr}^{3+}$ Phosphors | $\text{Li}_3\text{Ba}_2\text{Gd}_3(\text{MoO}_4)_8$<br>$\text{Sm}^{3+}$ Phosphors |
|------------------------------------|-----------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|
| Excitation Wavelength              | 452 nm                                                                            | 404 nm                                                                            |
| Emission Peaks                     |                                                                                   |                                                                                   |
| 594 nm                             | $^3\text{P}_0 \rightarrow ^3\text{H}_5$                                           | -                                                                                 |
| 618 nm                             | $^3\text{P}_0 \rightarrow ^3\text{H}_6$                                           | -                                                                                 |
| 645 nm                             | $^3\text{P}_0 \rightarrow ^3\text{F}_2$ (Prominent peak, red emission)            | -                                                                                 |
| 680 nm                             | $^3\text{P}_0 \rightarrow ^3\text{F}_3$                                           | -                                                                                 |
| 570 nm                             | -                                                                                 | $^4\text{G}_{5/2} \rightarrow ^6\text{H}_{5/2}$                                   |
| 605 nm                             | -                                                                                 | $^4\text{G}_{5/2} \rightarrow ^6\text{H}_{7/2}$ (Prominent peak, red emission)    |
| 649 nm                             | -                                                                                 | $^4\text{G}_{5/2} \rightarrow ^6\text{H}_{9/2}$                                   |
| Excitation Spectrum Range          | 250-350 nm (broad band, max intensity at 293 nm)                                  | 220-335 nm (broad band)                                                           |
| Additional Excitation Peaks        | 445-510 nm (fine lines, 4f-4f transitions)                                        | 330-500 nm (fine peaks, intra-4f transitions)                                     |
| 452 nm                             | $^3\text{H}_4 \rightarrow ^3\text{P}_2$                                           | -                                                                                 |
| 474 nm                             | $^3\text{H}_4 \rightarrow ^3\text{P}_1 + ^1\text{I}_6$                            | -                                                                                 |
| 487 nm                             | $^3\text{H}_4 \rightarrow ^3\text{P}_0$                                           | -                                                                                 |
| Effect of Dopant Concentration     |                                                                                   |                                                                                   |
| Increase in Relative Emission      | Up to x = 0.07 mol                                                                | Up to x = 0.07 mol                                                                |
| Maximum Intensity                  | x = 0.07 mol                                                                      | x = 0.07 mol                                                                      |
| Concentration Quenching            | Decrease in emission intensity beyond x = 0.07 mol                                | -                                                                                 |
| Optimal Concentration for Emission | x = 0.07 mol                                                                      | x = 0.07 mol                                                                      |

**Table 3.** CIE Chromaticity coordinates.

| S.No. | Sample                                                                   | CIE X coordinate | CIE Y coordinate |
|-------|--------------------------------------------------------------------------|------------------|------------------|
| 1     | $\text{Li}_3\text{Ba}_2\text{Gd}_3(\text{MoO}_4)_8:0.07 \text{ Pr}^{3+}$ | 0.686            | 0.302            |
| 2     | $\text{Li}_3\text{Ba}_2\text{Gd}_3(\text{MoO}_4)_8:0.07 \text{ Sm}^{3+}$ | 0.602            | 0.394            |
| 3     | $\text{CaMoO}_4:\text{Eu}^{3+}$                                          | 0.677            | 0.323            |
| 4     | $\text{Y}_2\text{O}_3:\text{Eu}^{3+}$                                    | 0.663            | 0.335            |

**Table 4.** Detailed Analysis of the Excitation and Emission Spectra of  $\text{Li}_3\text{Ba}_2\text{Gd}_3(\text{MoO}_4)_8$   $\text{Pr}^{3+}$  and  $\text{Li}_3\text{Ba}_2\text{Gd}_3(\text{MoO}_4)_8$   $\text{Sm}^{3+}$  Phosphors

| Parameter                           | $\text{Li}_3\text{Ba}_2\text{Gd}_3(\text{MoO}_4)_8$<br>$\text{Pr}^{3+}$ Phosphors                                                                                         | $\text{Li}_3\text{Ba}_2\text{Gd}_3(\text{MoO}_4)_8$<br>$\text{Sm}^{3+}$ Phosphors |
|-------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|
| Excitation Wavelength               | 452 nm                                                                                                                                                                    | 404 nm                                                                            |
| Monitoring Wavelength               | 645 nm                                                                                                                                                                    | 605 nm                                                                            |
| Excitation Spectrum                 |                                                                                                                                                                           |                                                                                   |
| Prominent Broad Band                | 250-350 nm, Max Intensity: 293 nm (Charge transfer transition)                                                                                                            | 220-335 nm (Charge transfer transition)                                           |
| Fine and Closed Absorption Lines    | 445-510 nm (4f-4f transitions of $\text{Pr}^{3+}$ ions)                                                                                                                   | 330-500 nm (Intra-4f transitions of $\text{Sm}^{3+}$ ions)                        |
| Prominent Peaks in Excitation Bands | 452 nm ( $^3\text{H}_4 \rightarrow ^3\text{P}_2$ ), 474 nm ( $^3\text{H}_4 \rightarrow ^3\text{P}_1 + ^1\text{I}_6$ ), 487 nm ( $^3\text{H}_4 \rightarrow ^3\text{P}_0$ ) | -                                                                                 |
| Emission Spectrum                   |                                                                                                                                                                           |                                                                                   |

| Parameter                             | $\text{Li}_3\text{Ba}_2\text{Gd}_3(\text{MoO}_4)_8$<br>$\text{Pr}^{3+}$ Phosphors                                                                                                                              | $\text{Li}_3\text{Ba}_2\text{Gd}_3(\text{MoO}_4)_8$<br>$\text{Sm}^{3+}$ Phosphors                                                                                                  |
|---------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Emission Peaks                        | 594 nm ( $^3\text{P}_0 \rightarrow ^3\text{H}_5$ ), 618 nm ( $^3\text{P}_0 \rightarrow ^3\text{H}_6$ ), 645 nm ( $^3\text{P}_0 \rightarrow ^3\text{F}_2$ ), 680 nm ( $^3\text{P}_0 \rightarrow ^3\text{F}_3$ ) | 570 nm ( $^4\text{G}_{5/2} \rightarrow ^6\text{H}_{5/2}$ ), 605 nm ( $^4\text{G}_{5/2} \rightarrow ^6\text{H}_{7/2}$ ), 649 nm ( $^4\text{G}_{5/2} \rightarrow ^6\text{H}_{9/2}$ ) |
| Prominent Emission Peak               | 645 nm ( $^3\text{P}_0 \rightarrow ^3\text{F}_2$ , Red emission)                                                                                                                                               | 605 nm ( $^4\text{G}_{5/2} \rightarrow ^6\text{H}_{7/2}$ , Red emission)                                                                                                           |
| <b>Effect of Dopant Concentration</b> |                                                                                                                                                                                                                |                                                                                                                                                                                    |
| Increase in Relative Emission         | Up to x = 0.07 mol                                                                                                                                                                                             | Up to x = 0.07 mol                                                                                                                                                                 |
| Maximum Intensity                     | x = 0.07 mol                                                                                                                                                                                                   | x = 0.07 mol                                                                                                                                                                       |
| Concentration Quenching               | Decrease in emission intensity beyond x = 0.07 mol                                                                                                                                                             | -                                                                                                                                                                                  |
| Optimal Concentration for Emission    | x = 0.07 mol                                                                                                                                                                                                   | x = 0.07 mol                                                                                                                                                                       |

## CONCLUSION

This work successfully demonstrates the synthesis of  $\text{Li}_3\text{Ba}_2\text{Gd}_3(\text{MoO}_4)_8$  ( $\text{RE}^{3+} = \text{Pr}^{3+}, \text{Sm}^{3+}$ ) phosphors using a novel microwave-assisted solid-state reaction method at ambient temperature. The synthesized phosphors exhibit strong red emission under specific excitation wavelengths, with  $\text{Li}_3\text{Ba}_2\text{Gd}_3(\text{MoO}_4)_8:0.07\text{Pr}^{3+}$  showing a prominent emission peak at 645 nm when excited at 450 nm, and  $\text{Li}_3\text{Ba}_2\text{Gd}_3(\text{MoO}_4)_8:0.07\text{Sm}^{3+}$  demonstrating intense emission lines at 605 nm under 404 nm excitation. The maximum optical intensity was obtained for 7 mol% doping concentration of both  $\text{Pr}^{3+}$  and  $\text{Sm}^{3+}$  ions. The  $\text{Pr}^{3+}$  ions, with their  $4f^2$  electronic configuration, provide a range of emissions including red, green, blue, and ultraviolet, making them versatile for various applications. Similarly,  $\text{Sm}^{3+}$  ions, with their  $4f^5$  configuration, produce strong orange-red fluorescence, indicating their potential for high-efficiency red emission. Comparative analysis with the conventional  $\text{Y}_2\text{O}_3:\text{Eu}^{3+}$  red phosphor reveals that the emission intensities of the synthesized  $\text{Li}_3\text{Ba}_2\text{Gd}_3(\text{MoO}_4)_8$  phosphors are comparable, positioning them as efficient alternatives for red-emitting materials. This highlights their suitability for integration into near-UV and blue light GaN-based white LEDs, suggesting their promise for next-generation solid-state lighting applications. The success of this synthesis method and the promising luminescence properties of the resulting phosphors pave the way for further research and optimization. Future studies can focus on enhancing the efficiency and stability of these phosphors, as well as exploring other rare-earth dopants to expand the range of achievable emissions. This research contributes significantly to the advancement of rare-earth-doped phosphors in advanced lighting technologies, potentially leading to more efficient, versatile, and sustainable lighting solutions.

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